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(54) **PECVD COATING METHODS FOR CAPPED SYRINGES, CARTRIDGES AND OTHER ARTICLES**

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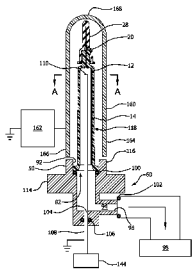
(57) **ABSTRACT**

A method is disclosed in which a vapor-deposited coating or layer is directly or indirectly applied to at least a portion of the internal wall of the barrel of a capped pre-assembly comprising a barrel, optionally a dispensing portion, and a cap. The cap is secured to the barrel and at least substantially isolates the distal opening of the dispensing portion from pressure conditions outside the cap. A vapor-deposited coating or layer is applied directly or indirectly to at least a portion of the internal wall of the barrel while the pre-assembly is capped. The coating or layer is applied under conditions effective to maintain communication from the barrel lumen to the exterior via the front opening, optionally further via the dispensing portion lumen if present, at the end of the applying step. The capped pre-assembly can be pressure tested easily and rapidly, for example with a test duration between 1 and 60 seconds, to determine whether it has container closure integrity.

15 Claims, 7 Drawing Sheets



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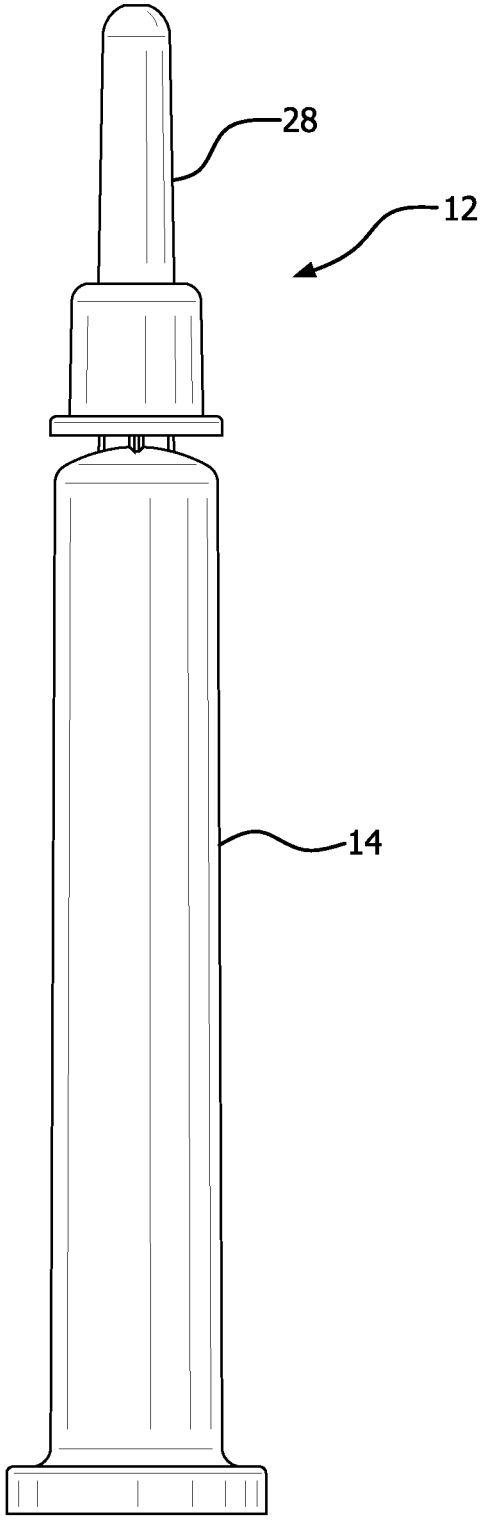
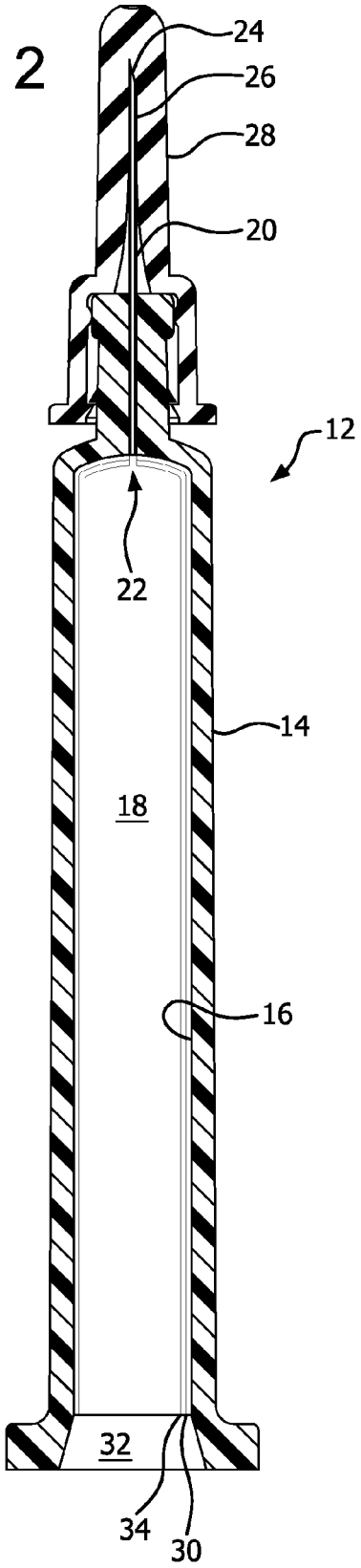


FIG. 1

FIG. 2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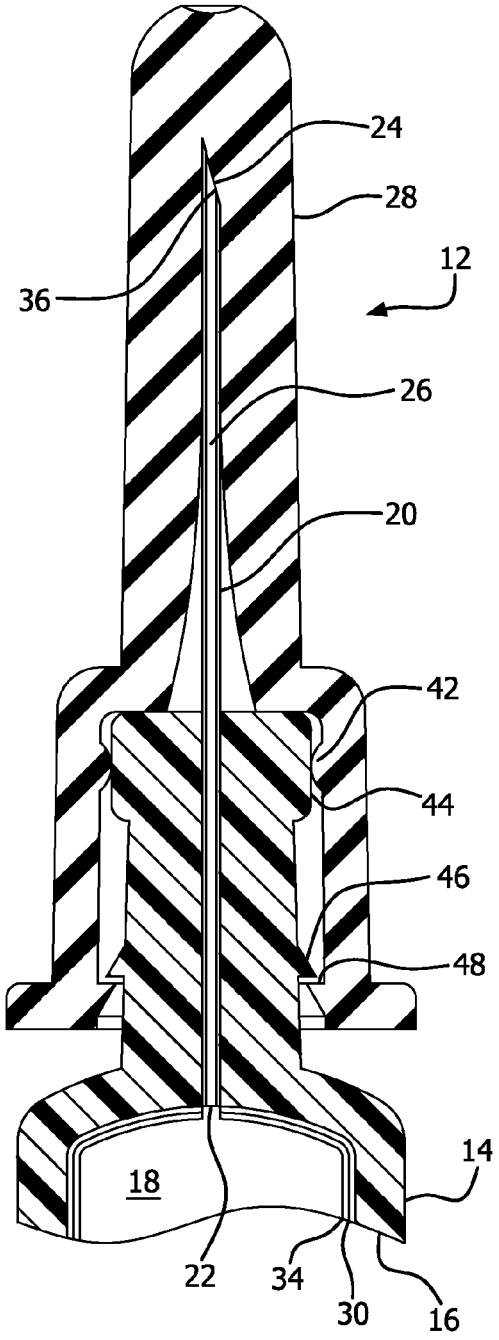
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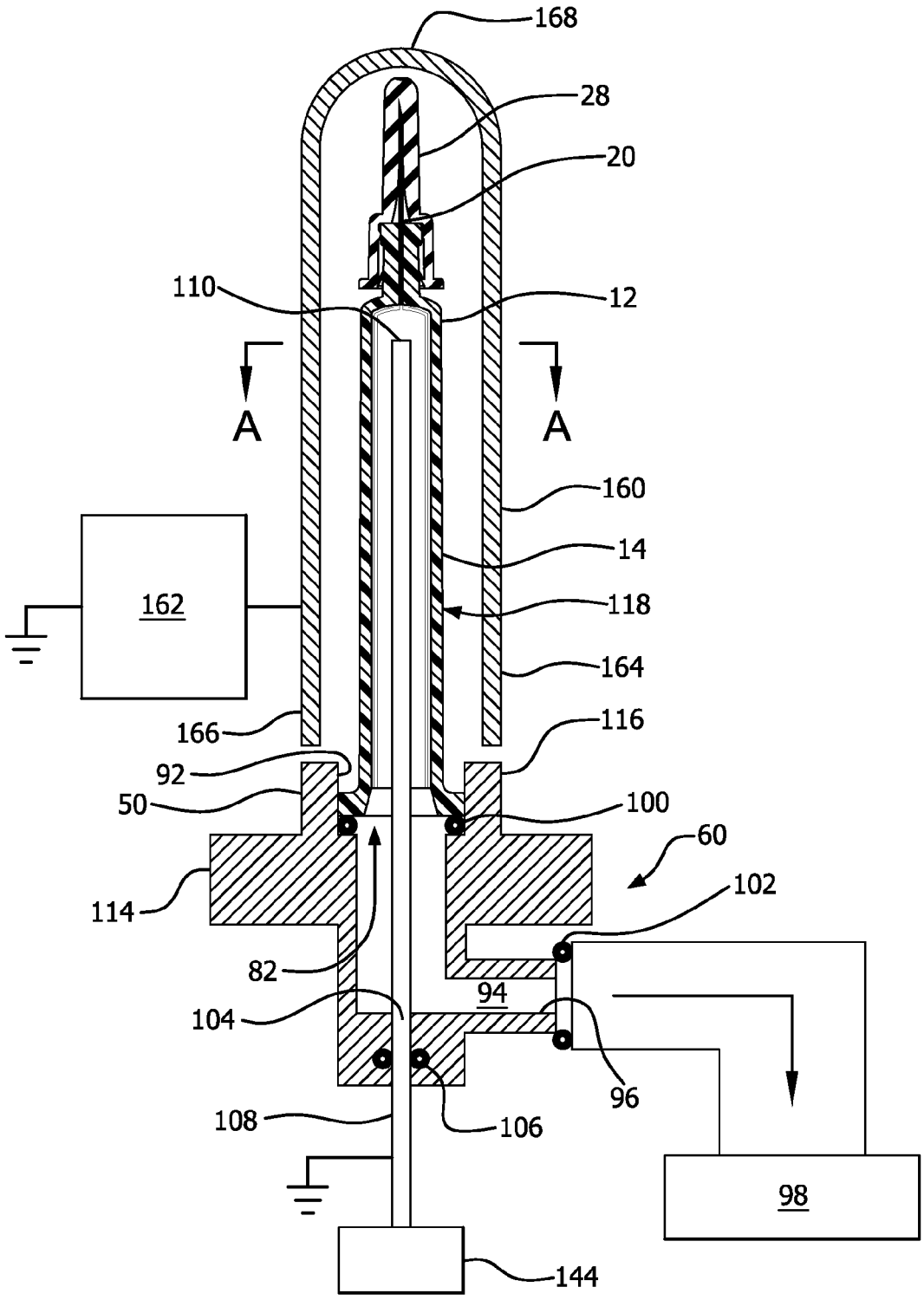
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FIG. 4

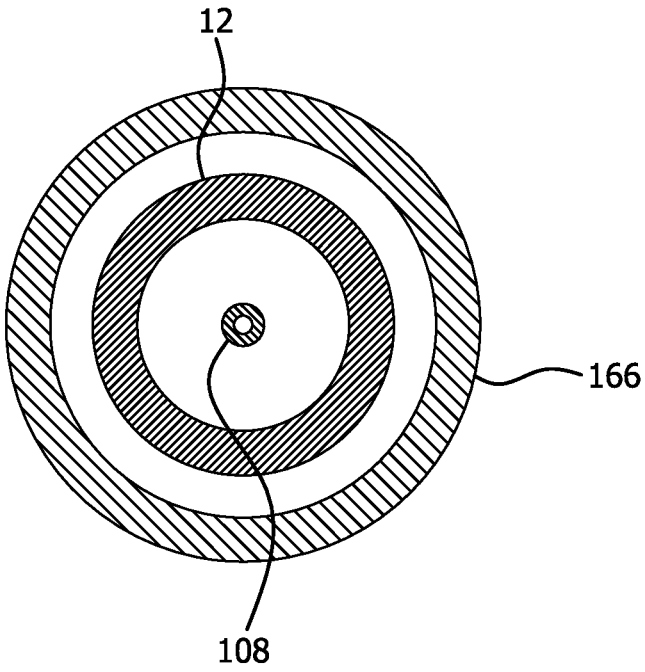

FIG. 5

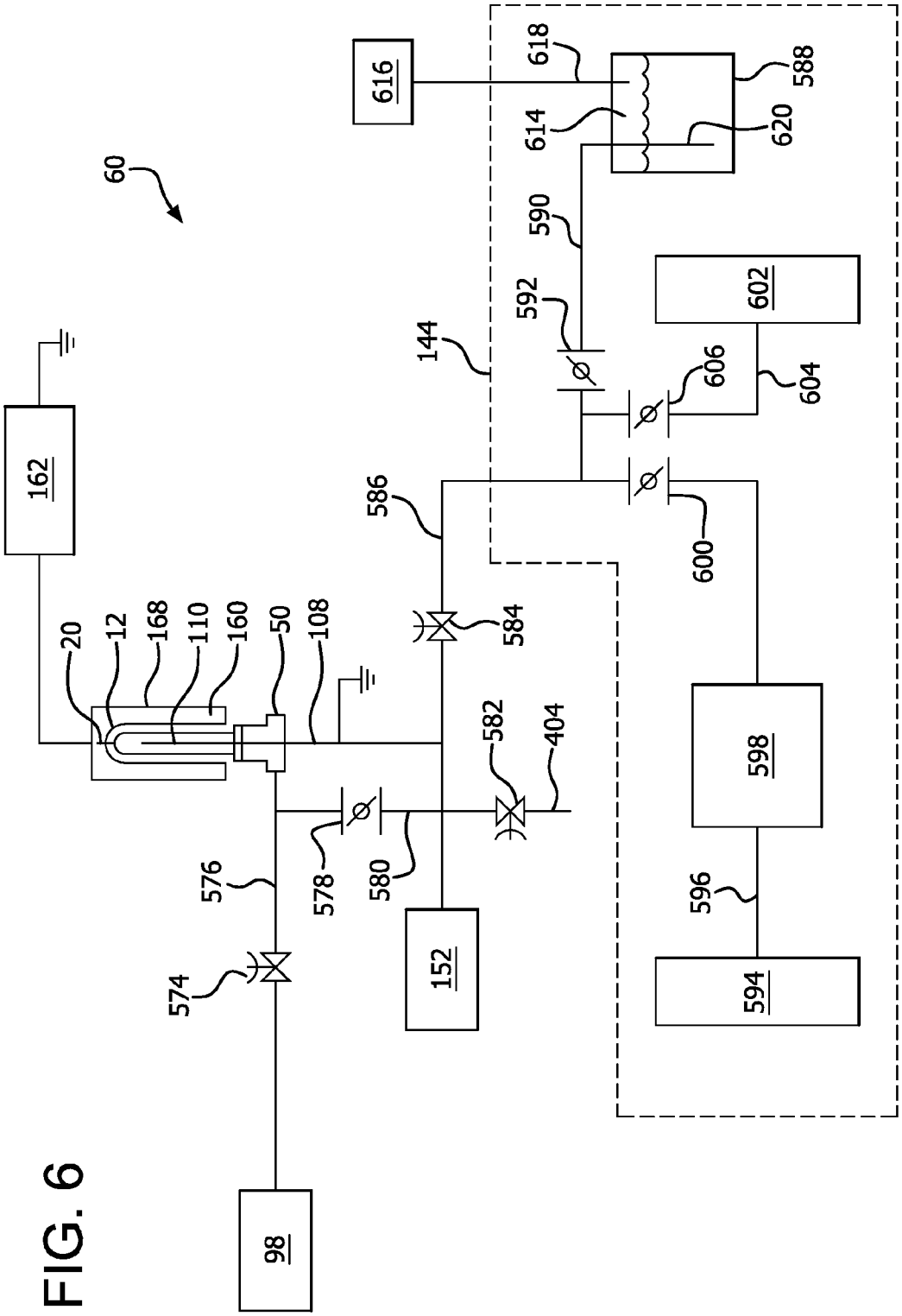
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FIG. 6

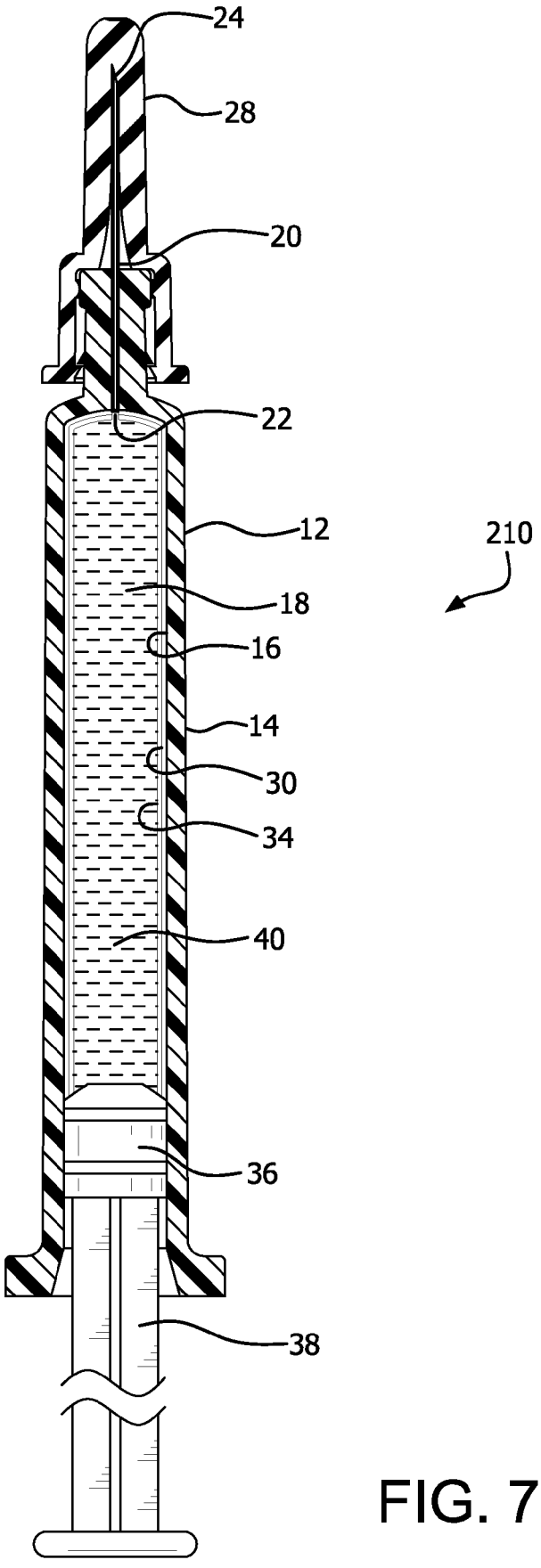

FIG. 7

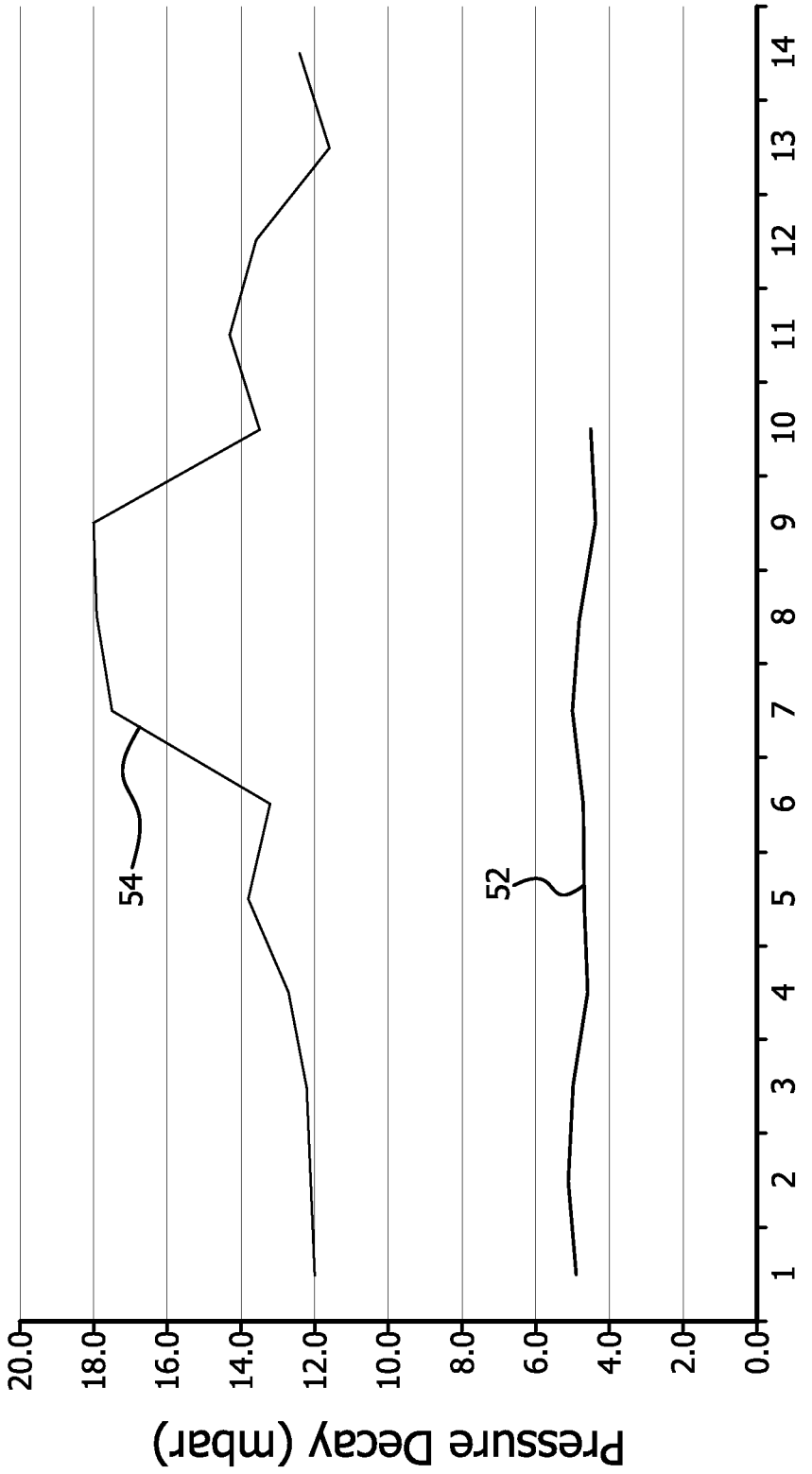
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FIG. 8

PECVD COATING METHODS FOR CAPPED SYRINGES, CARTRIDGES AND OTHER ARTICLES

This application is a continuation in part of

U.S. Ser. No. 13/169,811, filed Jun. 27, 2011, now pending; which is a divisional of

U.S. Ser. No. 12/779,007, filed May 12, 2010, now U.S. Pat. No. 7,985,188; which claims the priority of:

U.S. Provisional Ser. No. 61/222,727, filed Jul. 2, 2009;
U.S. Provisional Ser. No. 61/213,904, filed Jul. 24, 2009;
U.S. Provisional Ser. No. 61/234,505, filed Aug. 17, 2009;
U.S. Provisional Ser. No. 61/261,321, filed Nov. 14, 2009;
U.S. Provisional Ser. No. 61/263,289, filed Nov. 20, 2009;
U.S. Provisional Ser. No. 61/285,813, filed Dec. 11, 2009;
U.S. Provisional Ser. No. 61/298,159, filed Jan. 25, 2010;
U.S. Provisional Ser. No. 61/299,888, filed Jan. 29, 2010;
U.S. Provisional Ser. No. 61/318,197, filed Mar. 26, 2010; and

U.S. Provisional Ser. No. 61/333,625, filed May 11, 2010; and this application claims the priority of:

U.S. Provisional Ser. No. 61/636,377, filed Apr. 20, 2012.

All of the above patent applications and patent are incorporated here by reference in their entirety, including the applications they incorporate by reference.

FIELD OF THE INVENTION

The present invention relates to the technical field of coated surfaces, for example interior surfaces of pharmaceutical packages or other vessels for storing or other contact with fluids. Examples of suitable fluids include foods or biologically active compounds or body fluids, for example blood. The present invention also relates to a pharmaceutical package or other vessel and to a method for coating or layer an inner or interior surface of a pharmaceutical package or other vessel. The present invention also relates more generally to medical devices, including devices other than packages or vessels, for example catheters.

The present disclosure also relates to improved methods for processing pharmaceutical packages or other vessels, for example multiple identical pharmaceutical packages or other vessels used for pharmaceutical preparation storage and delivery, venipuncture and other medical sample collection, and other purposes. Such pharmaceutical packages or other vessels are used in large numbers for these purposes, and must be relatively economical to manufacture and yet highly reliable in storage and use.

BACKGROUND OF THE INVENTION

One important consideration in manufacturing pre-filled syringes and cartridges or other vessels (such as vials) for storing or other contact with fluids, for example, is that the contents of the pharmaceutical package or other vessel desirably will have a substantial shelf life. During this shelf life, it is important to isolate the material filling the pharmaceutical package or other vessel from the vessel wall containing it, or from barrier coating or layers or other functional coating or layers applied to the pharmaceutical package or other vessel wall to avoid leaching material from the pharmaceutical package or other vessel wall, barrier coating or layer, or other functional coating or layers into the prefilled contents or vice versa.

Commonly, after it is filled, a prefilled syringe or cartridge is capped at the distal end, as with a needle shield or other type of cap, and is closed at the proximal end by its drawn plunger tip or piston. The prefilled syringe or cartridge can be wrapped in a sterile package before use. To use the prefilled syringe or cartridge, the packaging and needle shield or other type of cap are removed, optionally a hypodermic needle or other type of dispenser is attached (if not already present), the delivery conduit or syringe is moved to a use position (such as by inserting the hypodermic needle into a patient's blood vessel or into apparatus to be rinsed with the contents of the syringe), and the plunger tip or piston is advanced in the barrel to inject the contents of the barrel. If a cartridge is being used, it is also placed into a mechanism that mechanically advances the piston to make an injection, for example using an injection spring.

An important consideration regarding medical syringes and cartridges, in particular prefilled syringes and cartridges, is to ensure that the prefilled syringe or cartridge has container closure integrity, meaning that it has been determined to be sterile, and not subject to subsequent microbiological contamination, by a mechanical, non-destructive test method. Other important considerations are that when the syringe or cartridge is being manufactured and before it has been filled, it does not have defects that would prevent the filled package from having the necessary container closure integrity. It is also important to manufacture a medical syringe or cartridge that is economical to manufacture, yet will provide the necessary container closure integrity, which can be verified by a test performed on every piece manufactured (a concept sometimes referred to as "100% inspection").

SUMMARY OF THE INVENTION

An aspect of the invention is a method in which a vapor-deposited coating or layer is directly or indirectly applied to at least a portion of the internal wall of the barrel of a capped pre-assembly.

A capped pre-assembly is provided comprising a barrel, optionally a dispensing portion, and a cap.

The barrel has an internal wall defining a barrel lumen and a front opening through the internal wall.

The optional dispensing portion can be secured to the barrel and includes a distal opening and a dispensing portion lumen. The distal opening is located outside the barrel. The dispensing portion lumen communicates between the front opening of the barrel and the distal opening of the dispensing portion.

The cap is secured to the barrel and at least substantially isolates the front opening of the barrel and (if a dispensing portion is present) the distal opening of the dispensing portion from pressure conditions outside the cap.

A vapor-deposited coating or layer is applied directly or indirectly to at least a portion of the internal wall of the barrel. The coating or layer is applied while the pre-assembly is capped. The coating or layer is applied under conditions effective to maintain communication between the barrel lumen and the exterior via the front opening at the end of the applying step.

In an optional further elaboration of the method, the capped pre-assembly can be pressure tested easily and rapidly, for example with a test duration between 1 and 60 seconds, to determine whether it has container closure integrity.

Other aspects of the invention will become apparent from the present description, claims, and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an elevation view of a capped pre-assembly according to an embodiment of the disclosure.

FIG. **2** is a longitudinal section of the capped pre-assembly of FIG. **1**.

FIG. **3** is an enlarged fragmentary view of the capped pre-assembly of FIGS. **1** and **2**.

FIG. **4** is a schematic longitudinal section of the capped pre-assembly of FIGS. **1** and **2** seated on a chemical vapor deposition coating station.

FIG. **5** is a section taken along section lines A-A of FIG. **4**.

FIG. **6** is a schematic view showing more details of the chemical vapor deposition coating station shown in FIGS. **4** and **5**.

FIG. **7** is a view similar to FIG. **2** of the capped pre-assembly of FIGS. **1-6**, filled with a pharmaceutical preparation and fitted with a plunger tip or piston to define a pre-filled syringe. In the option shown, a plunger tip and plunger are installed.

FIG. **8** is a plot of pressure decay for 14 different samples made according to the working example set out below.

The following reference characters are used in the drawing figures:

12	Capped pre-assembly
14	Barrel
16	Internal wall
18	Barrel lumen
20	Dispensing portion
22	Front opening
24	Distal opening
26	Dispensing portion lumen
27	Cap
30	(first) Vapor-deposited coating or layer
32	Opening
34	(second) vapor-deposited coating or layer
36	Plunger tip or piston
38	Plunger rod
40	Fluid material
42	Rib
44	Cylindrical surface
46	Barb
48	Catch
50	Vessel holder
52	Plot
54	Plot
60	coating station
82	Opening
84	Closed end
92	Vessel port
94	Vacuum duct
96	Vacuum port
98	Vacuum source
100	O-ring (of 92)
102	O-ring (of 96)
104	Gas inlet port
106	O-ring (of 100)
108	Probe (counter electrode)
110	Gas delivery port (of 108)
114	Housing (of 50 or 112)
116	Collar
118	Exterior surface (of 80)
144	PECVD gas source
152	Pressure gauge
160	Electrode
162	Power supply
164	Sidewall (of 160)
166	Sidewall (of 160)
168	Closed end (of 160)
200	Electrode
210	Pharmaceutical package
404	Exhaust
574	Main vacuum valve
576	Vacuum line
578	Manual bypass valve
580	Bypass line
582	Vent valve

-continued

584	Main reactant gas valve
586	Main reactant feed line
588	Organosilicon liquid reservoir
590	Organosilicon feed line (capillary)
592	Organosilicon shut-off valve
594	Oxygen tank
596	Oxygen feed line
598	Mass flow controller
600	Oxygen shut-off valve
602	Additional reservoir
604	Feed line
606	Shut-off valve
614	Headspace
616	Pressure source
618	Pressure line
620	Capillary connection

The present invention will now be described more fully, with reference to the accompanying drawings, in which several embodiments are shown. This invention can, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth here. Rather, these embodiments are examples of the invention, which has the full scope indicated by the language of the claims. Like numbers refer to like or corresponding elements throughout. The following disclosure relates to all embodiments unless specifically limited to a certain embodiment.

DEFINITION SECTION

In the context of the present invention, the following definitions and abbreviations are used:

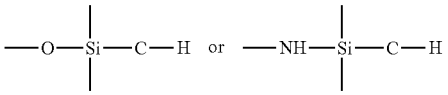
In the present Figures, the capped pre-assembly **12** is configured as a syringe. The capped pre-assembly **12** can optionally be completed to form a syringe by adding a plunger tip or piston **36** (two interchangeable names for the same structure) and a plunger rod **38**. The internal wall **16** can define at least a portion of the barrel **14**. The plunger tip or piston **36** can be a relatively sliding part of the syringe, with respect to the barrel **14**. The term "syringe," however, is broadly defined to include cartridges, injection "pens," and other types of barrels or reservoirs adapted to be assembled with one or more other components to provide a functional syringe. "Syringe" is also broadly defined to include related articles such as auto-injectors, which provide a mechanism for dispensing the contents.

RF is radio frequency.

The term "at least" in the context of the present invention means "equal or more" than the integer following the term. The word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality unless indicated otherwise. Whenever a parameter range is indicated, it is intended to disclose the parameter values given as limits of the range and all values of the parameter falling within said range.

"First" and "second" or similar references to, for example, coating or layers refer to the minimum number of coating or layers that are present, but do not necessarily represent the order or total number of coating or layers. These terms do not limit the number of coating or layers or the particular processing carried out at the respective stations.

For purposes of the present invention, a "precursor" is a compound having at least one of the linkages:



which is a tetravalent silicon atom connected to an oxygen or nitrogen atom and an organic carbon atom (an organic carbon atom being a carbon atom bonded to at least one hydrogen atom). A volatile organosilicon precursor, defined as such a precursor that can be supplied as a vapor in a PECVD apparatus, is an optional organosilicon precursor. Optionally, the organosilicon precursor is selected from the group consisting of a linear siloxane, a monocyclic siloxane, a polycyclic siloxane, a polysilsesquioxane, an alkyl trimethoxysilane, a linear silazane, a monocyclic silazane, a polycyclic silazane, a polysilsesquiazane, and a combination of any two or more of these precursors.

The feed amounts of PECVD precursors, gaseous reactant or process gases, and carrier gas are sometimes expressed in "standard volumes" in the specification and claims. The standard volume of a charge or other fixed amount of gas is the volume the fixed amount of the gas would occupy at a standard temperature and pressure (without regard to the actual temperature and pressure of delivery). Standard volumes can be measured using different units of volume, and still be within the scope of the present disclosure and claims. For example, the same fixed amount of gas could be expressed as the number of standard cubic centimeters, the number of standard cubic meters, or the number of standard cubic feet. Standard volumes can also be defined using different standard temperatures and pressures, and still be within the scope of the present disclosure and claims. For example, the standard temperature might be 0° C. and the standard pressure might be 760 Torr (as is conventional), or the standard temperature might be 20° C. and the standard pressure might be 1 Torr. But whatever standard is used in a given case, when comparing relative amounts of two or more different gases without specifying particular parameters, the same units of volume, standard temperature, and standard pressure are to be used relative to each gas, unless otherwise indicated.

The corresponding feed rates of PECVD precursors, gaseous reactant or process gases, and carrier gas are expressed in standard volumes per unit of time in the specification. For example, in the working examples the flow rates are expressed as standard cubic centimeters per minute, abbreviated as sccm. As with the other parameters, other units of time can be used, such as seconds or hours, but consistent parameters are to be used when comparing the flow rates of two or more gases, unless otherwise indicated.

The term "at least" in the context of the present invention means "equal or more" than the integer following the term. Thus, a barrel and dispensing portion in the context of the present invention has one or more openings. One or two openings, like the openings of a sample tube (one opening) or a syringe barrel (two openings) are preferred. If the vessel has two openings, they can be of same or different size. If there is more than one opening, one opening can be used for the gas inlet for a PECVD coating or layer method according to the present invention, while the other openings are capped.

Empirical compositions represented by the formulas SiO_x, SiO_xC_y, and $SiO_xC_yH_z$ are referred to in this specification. The values of x, y, and z used throughout this specification should be understood as ratios or an empirical formula (for example for a coating or layer), rather than as a limit on the number or type of atoms in a molecule. For example, octamethylcyclotetrasiloxane, which has the molecular composition $Si_4O_4C_8H_{24}$, can be described by the following empirical formula, arrived at by dividing each of w, x, y, and z in the molecular formula by 4, the largest common factor: $SiO_1C_2H_6$. The values of x, y, and z are also not limited to integers. For example, (acyclic) octamethyltrisiloxane, molecular composition $Si_3O_2C_8H_{24}$, is reducible to $SiO_{0.67}C_{2.67}H_8$. Also, although $SiO_xC_yH_z$ is described as equivalent to SiO_xC_y, it is not necessary to show the presence of hydrogen in any proportion to show the presence of SiO_xC_y.

A "protective coating or layer" according to the present invention is a coating or layer that protects an underlying surface, coating or layer from a fluid composition contacting the coating or layer. The present pH protective coating or layers optionally can have a composition according to the empirical composition $Si_wO_xC_yH_z$, (or its equivalent SiO_xC_y) as defined herein. It generally has an atomic ratio $Si_wO_xC_y$ (or its equivalent SiO_xC_y) wherein w is 1, x is from about 0.5 to about 2.4, y is from about 0.6 to about 3.

Typically, expressed as the formula $Si_wO_xC_y$, the atomic ratios of Si, O, and C in the "protective coating or layer" are, as several options:

Si 100: O 50-150: C 90-200 (i.e. w=1, x=0.5 to 1.5, y=0.9 to 2);

Si 100: O 70-130: C 90-200 (i.e. w=1, x=0.7 to 1.3, y=0.9 to 2)

Si 100: O 80-120: C 90-150 (i.e. w=1, x=0.8 to 1.2, y=0.9 to 1.5)

Si 100: O 90-120: C 90-140 (i.e. w=1, x=0.9 to 1.2, y=0.9 to 1.4), or

Si 100: O 92-107: C 116-133 (i.e. w=1, x=0.92 to 1.07, y=1.16 to 1.33)

The atomic ratio can be determined by XPS (X-ray photoelectron spectroscopy). Taking into account the H atoms, which are not measured by XPS, the coating or layer may thus in one aspect have the formula $Si_wO_xC_yH_z$ (or its equivalent SiO_xC_y), for example where w is 1, x is from about 0.5 to about 2.4, y is from about 0.6 to about 3, and z is from about 2 to about 9. Typically, such coating or layer would hence contain 36% to 41% carbon normalized to 100% carbon plus oxygen plus silicon.

One of the optional embodiments of the present invention is a syringe part, for example a syringe or cartridge barrel, particularly as part of a capped pre-assembly, coated with a pH protective coating or layer.

"Slidably" means that the plunger tip or piston, closure, or other movable part is permitted to slide in a syringe barrel, cartridge, or other vessel.

DETAILED DESCRIPTION

Referring to the Figures, an aspect of the invention is a method in which a vapor-deposited coating or layer **30** is directly or indirectly applied to at least a portion of the internal wall **16** of the barrel **14** of a capped pre-assembly **12**.

A capped pre-assembly **12** is provided comprising a barrel **14**, optionally a dispensing portion **20**, and a cap **28**. The capped pre-assembly **12** can be a complete article or it can be a portion of a complete article adapted to dispense fluid, such as a syringe, a cartridge, a catheter, or other article.

The barrel **14** has an internal wall **16** defining a barrel lumen **18** and a front opening **22** through the internal wall **16**. Optionally in any embodiment, the barrel **14** can further include a another opening **32** spaced from the dispensing

portion **20** and communicating through the internal wall **16**. Such an opening is conventional, for example, in a syringe or cartridge, where a typical example is the back opening **32** of a prefilled syringe barrel, through which the piston or plunger **36** is inserted after the barrel lumen **18** is filled with a suitable pharmaceutical preparation or other fluid material **40** to be dispensed.

The barrel **14** is formed, for example, by molding, although the manner of its formation is not critical and it can also be formed, for example, by machining a solid preform. Preferably, the barrel is molded by injection molding thermoplastic material, although it can also be formed by blow molding or a combined method.

As one preferred example, the barrel **14** can be formed by placing a dispensing portion **20** as described below in an injection mold and injection molding thermoplastic material about the dispensing portion, thus forming the barrel and securing the dispensing portion to the barrel. Alternatively, the dispensing portion (if present) and the barrel can be molded or otherwise formed as a single piece, or can be formed separately and joined in other ways. The barrel of any embodiment can be made of any suitable material. Several barrel materials particularly contemplated are COC (cyclic olefin copolymer), COP (cyclic olefin polymer), PET (polyethylene terephthalate), and polypropylene.

The optional dispensing portion **20** of the capped pre-assembly **12** is provided to serve as an outlet for fluid dispensed from the barrel lumen **18** of a completed article made from the capped pre-assembly **12**. One example of a suitable dispensing portion illustrated in the Figures is a hypodermic needle **20**.

Alternatively, in any embodiment the dispensing portion **20** can instead be a needle-free dispenser. One example of a suitable needle-free dispenser is a blunt or flexible dispensing portion intended to be received in a complementary coupling to transfer fluid material **40**. Such blunt or flexible dispensing portions are well known for use in syringes, intravenous infusion systems, and other systems and equipment to dispense material while avoiding the hazard of working with a sharp needle that may accidentally stick a health professional or other person. Another example of a needle-free dispenser is a fluid jet or spray injection system that injects a free jet or spray of fluid directly through a patient's skin, without the need for an intermediate needle. Any type of dispensing portion **20**, whether a hypodermic needle or any form of needle-free dispenser, is contemplated for use according to any embodiment of the present invention.

The dispensing portion **20** is secured to the barrel **14** and includes a distal opening **24** and a dispensing portion lumen **26**. The front opening **22** communicates with the barrel lumen **18**. The distal opening **24** is located outside the barrel **14**. The dispensing portion lumen **26** communicates between the front opening **22** and the distal opening **24** of the dispensing portion **20**. In the illustrated embodiment, the distal opening **24** is at the sharpened tip of a hypodermic needle **20**.

The cap **28** is secured to the barrel **14** and at least substantially isolates the front opening **22** and the distal opening **24** of the dispensing portion **20** from pressure conditions outside the cap **28**. Optionally in any embodiment, the cap **28** sufficiently isolates portions of the assembly **12** to provide a sufficient bio-barrier to facilitate safe use of the capped pre-assembly **12** for transdermal injections.

The cap **28** can isolate the distal opening **24** in various ways. Effective isolation can be provided at least partially due to contact between the cap **28** and the distal opening **24**, as shown in present FIGS. **2**, **3**, **4**, and **7**. In the illustrated embodiment, the tip of the dispensing portion **20** is buried in the material of the cap **28**. Alternatively in any embodiment, effective isolation can be provided at least partially due to contact between the cap **28** and the barrel **14**, as also shown in present FIGS. **2**, **3**, **4**, and **7**. In the illustrated embodiment, the primary line of contact between the cap **28** and the barrel **14** is at a rib **42** (best seen in FIG. **3**) encircling and seated against a generally cylindrical surface **44** at the nose of the barrel **14**. Alternatively in any embodiment, effective isolation can be provided due to both of these types of contact as illustrated in FIGS. **2-3**, or in other ways, without limitation.

The cap **28** of any embodiment optionally has a latching mechanism, best shown in FIG. **3**, including a barb **46** and a catch **48** which engage to hold the cap **28** in place. The catch **48** is made of sufficiently resilient material to allow the cap **28** to be removed and replaced easily.

If the dispensing portion **20** is a hypodermic needle, the cap **28** can be a specially formed needle shield. The original use of a needle shield is to cover the hypodermic needle before use, preventing accidental needle sticks and preventing contamination of the needle before it is injected in a patient or an injection port. A comparable cap preferably is used, even if the dispensing portion **20** is a needle-free dispenser, to prevent contamination of the dispenser during handling.

The cap **28** can be formed in any suitable way. For example, the cap **28** can be formed by molding thermoplastic material. Optionally in any embodiment, the thermoplastic material is elastomeric material or other material that is suitable for forming a seal. One suitable category of elastomeric materials is known generically as thermoplastic elastomer (TPE). An example of a suitable thermoplastic elastomer for making a cap **28** is Stelmi® Formulation 4800 (flexible cap formulation). Any other material having suitable characteristics can instead be used in any embodiment.

As another optional feature in any embodiment the cap **28** can be sufficiently permeable to a sterilizing gas to sterilize the portions of the assembly **12** isolated by the cap. One example of a suitable sterilizing gas is ethylene oxide. Caps **28** are available that are sufficiently permeable to the sterilizing gas that parts isolated by the cap can nonetheless be sterilized. An example of a cap formulation sufficiently permeable to accommodate ethylene oxide gas sterilization is Stelmi® Formulation 4800.

Thus, an optional step in the present methods is sterilizing the capped pre-assembly **12** using a sterilizing gas. Sterilization can be performed at any suitable step, such as sterilizing the capped pre-assembly **12** alone or sterilizing a complete pre-filled syringe assembly after it is filled with a suitable pharmaceutical preparation or other material.

When carrying out the present method, a vapor-deposited coating or layer **30** is applied directly or indirectly to at least a portion of the internal wall **16** of the barrel **14**. The coating or layer **30** is applied while the pre-assembly **12** is capped. The coating or layer **30** is applied under conditions effective to maintain communication between the barrel lumen **18** and the dispensing portion lumen **26** via the front opening **22** at the end of the applying step.

In any embodiment the vapor-deposited coating or layer **30** optionally can be applied through the opening **32**.

In any embodiment the vapor-deposited coating or layer **30** optionally can be applied by introducing a vapor-phase precursor material through the opening and employing chemical vapor deposition to deposit a reaction product of the precursor material on the internal wall of the barrel.

In any embodiment the vapor-deposited coating or layer (**30**) optionally can be applied by flowing a precursor reactant vapor material through the opening and employing chemical vapor deposition to deposit a reaction product of the precursor reactant vapor material on the internal wall of the barrel.

In any embodiment the reactant vapor material optionally can be a precursor.

In any embodiment the reactant vapor material optionally can be an organosilicon precursor.

In any embodiment the reactant vapor material optionally can be an oxidant gas.

In any embodiment the reactant vapor material optionally can be oxygen.

In any embodiment the reactant vapor material optionally can include a carrier gas.

In any embodiment the reactant vapor material optionally can include helium, argon, krypton, xenon, neon, or a combination of two or more of these.

In any embodiment the reactant vapor material optionally can include argon.

In any embodiment the reactant vapor material optionally can be a precursor material mixture with one or more oxidant gases in a partial vacuum through the opening and employing chemical vapor deposition to deposit a reaction product of the precursor material mixture on the internal wall of the barrel.

In any embodiment the reactant vapor material optionally can be passed through the opening at sub-atmospheric pressure.

In any embodiment the chemical vapor deposition optionally can be plasma-enhanced chemical vapor deposition.

In any embodiment the vapor-deposited coating or layer optionally can be a gas barrier coating or layer.

In any embodiment the vapor-deposited coating or layer optionally can be an oxygen barrier coating or layer.

In any embodiment the vapor-deposited coating or layer is a water vapor barrier coating or layer.

In any embodiment the vapor-deposited coating or layer optionally can be a solvent barrier coating or layer.

In any embodiment the vapor-deposited coating or layer optionally can be a water barrier coating or layer.

In any embodiment the vapor-deposited coating or layer optionally can be a solvent barrier coating or layer for a solvent comprising a co-solvent used to increase drug solubilization.

In any embodiment the vapor-deposited coating or layer optionally can be a barrier coating or layer for water, glycerin, propylene glycol, methanol, ethanol, n-propanol, isopropanol, acetone, benzyl alcohol, polyethylene glycol, cotton seed oil, benzene, dioxane, or combinations of any two or more of these.

In any embodiment the vapor-deposited coating or layer optionally can be a solute barrier coating or layer. Examples of solutes in drugs usefully excluded by a barrier layer in any embodiment include antibacterial preservatives, antioxidants, chelating agents, pH buffers, and combinations of any of these.

In any embodiment the vapor-deposited coating or layer optionally can be a metal ion barrier coating or layer.

In any embodiment the vapor-deposited coating or layer optionally can be a barrel wall material barrier coating or layer, to prevent or reduce the leaching of barrel material such as any of the base barrel resins mentioned previously and any other ingredients in their respective compositions.

The vapor deposited coating or layer for any embodiment defined in this specification (unless otherwise specified in a particular instance) optionally can be a coating or layer, optionally applied by PECVD as indicated in U.S. Pat. No. 7,985,188. The vapor deposited coating or layer can be a barrier coating or layer, optionally a barrier coating or layer characterized as an "SiO_x" coating or layer containing silicon, oxygen, and optionally other elements, in which x, the ratio of oxygen to silicon atoms, optionally can be from about 1.5 to about 2.9, or 1.5 to about 2.6, or about 2. These alternative definitions of x apply to any use of the term SiO_x in this specification. The barrier coating or layer optionally can be applied, for example to the interior of a pharmaceutical package or other vessel, for example a sample collection tube, a syringe barrel, a vial, or another type of vessel. The SiO_x coating or layer is particularly contemplated as a barrier to oxygen ingress or egress and a solute barrier to prevent migration of drug constituents (as in the barrel lumen **18** of a prefilled syringe or cartridge) into the barrel wall or the migration of barrel wall constituents into the drug or other contents of the barrel lumen.

In any embodiment plasma optionally can be generated in the barrel lumen **18** by placing an inner electrode into the barrel lumen **18** through the opening **32**, placing an outer electrode outside the barrel **14** and using the electrodes to apply plasma-inducing electromagnetic energy which optionally can be microwave energy, radio frequency energy, or both in the barrel lumen **18**.

In any embodiment the electromagnetic energy optionally can be direct current.

In any embodiment the electromagnetic energy optionally can be alternating current. The alternating current optionally can be modulated at frequencies including audio, or microwave, or radio, or a combination of two or more of audio, microwave, or radio.

In any embodiment the electromagnetic energy optionally can be applied across the barrel lumen (**18**).

In any embodiment, in addition to applying a first coating or layer as described above, the method optionally can include applying second or further coating or layer of the same material or a different material. As one example useful in any embodiment, particularly contemplated if the first coating or layer is an SiO_x barrier coating or layer, a further coating or layer can be placed directly or indirectly over the barrier coating or layer. One example of such a further coating or layer useful in any embodiment is a pH protective coating or layer

The pH protective coating or layer optionally can be applied over at least a portion of the SiO_x coating or layer to protect the SiO_x coating or layer from contents stored in a vessel, where the contents otherwise would be in contact with the SiO_x coating or layer. The pH protective coating or layers or layers are particularly contemplated to protect an SiOx barrier layer of a prefilled syringe or cartridge that is exposed to contents, such as a pharmaceutical preparation, having a pH between 4 and 9, alternatively between 4 and 8, alternatively between 5 and 9. Such pharmaceutical preparations have been found to attack and remove the SiOx coating or layer if unprotected by a protective coating or layer.

Thus, in any embodiment, after the applying step, another vapor-deposited coating **34** optionally can be applied directly or indirectly over the coating **30**, while the preassembly **12** is capped, under conditions effective to maintain communication between the barrel lumen **18** and the dispensing portion lumen **26** via the front opening **22** at the end of applying the second vapor-deposited coating **34**.

In any embodiment, the other vapor-deposited coating **34** can be a pH protective coating or layer.

In any embodiment, the pH protective coating or layer can include or consist essentially of SiO_xC_y or SiN_xC_y wherein x is from about 0.5 to about 2.4, optionally about 1.1, and y is from about 0.6 to about 3, optionally about 1.1.

In any embodiment, the pH protective coating or layer can include or consist essentially of $SiO_xC_yH_z$, in which x is from about 0.5 to about 2.4, optionally from about 0.5 to 1, y is from about 0.6 to about 3, optionally from about 2 to about 3, and z is from about 2 to about 9, optionally from 6 to about 9.

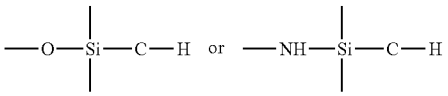
Optionally in any embodiment, the pH protective coating or layer can be applied as the first or sole vapor-deposited coating or layer (**30**), instead of or in addition to its application as a further layer. This expedient may be useful, for example, where the barrel is made of glass. The presently disclosed pH protective coating or layer also reduces the dissolution of glass by contents having the pH values indicated as attacking SiO_x coatings or layers.

Surprisingly, it has been found that the above stated coatings or layers can be applied to the capped pre-assembly **12** with substantially no deposition of the vapor-deposited coating **30** in the dispensing portion lumen **26**. This is shown by a working example below.

Precursors

The precursor for the SiO_x barrier coating or layer or for the pH protective coating or layer can include any of the following precursors useful for PECVD. The precursor for the PECVD pH protective coating or layer of the present invention optionally can be broadly defined as an organometallic precursor. An organometallic precursor is defined in this specification as comprehending compounds of metal elements from Group III and/or Group IV of the Periodic Table having organic residues, for example hydrocarbon, aminocarbon or oxycarbon residues. Organometallic compounds as presently defined include any precursor having organic moieties bonded to silicon or other Group III/IV metal atoms directly, or optionally bonded through oxygen or nitrogen atoms. The relevant elements of Group III of the Periodic Table are Boron, Aluminum, Gallium, Indium, Thallium, Scandium, Yttrium, and Lanthanum, Aluminum and Boron being preferred. The relevant elements of Group IV of the Periodic Table are Silicon, Germanium, Tin, Lead, Titanium, Zirconium, Hafnium, and Thorium, with Silicon and Tin being preferred. Other volatile organic compounds can also be contemplated. However, organosilicon compounds are preferred for performing present invention.

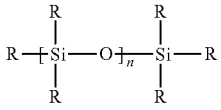
An organosilicon precursor is contemplated, where an "organosilicon precursor" is defined throughout this specification most broadly as a compound having at least one of the linkages:



The first structure immediately above is a tetravalent silicon atom connected to an oxygen atom and an organic carbon atom (an organic carbon atom being a carbon atom bonded to at least one hydrogen atom). The second structure immediately above is a tetravalent silicon atom connected to an —NH— linkage and an organic carbon atom (an organic carbon atom being a carbon atom bonded to at least one hydrogen atom). Optionally, the organosilicon precursor is selected from the group consisting of a linear siloxane, a monocyclic siloxane, a polycyclic siloxane, a polysilsesquioxane, a linear silazane, a monocyclic silazane, a polycyclic silazane, a polysilsesquiazane, and a combination of any two or more of these precursors. Also contemplated as a precursor, though not within the two formulas immediately above, is an alkyl trimethoxysilane.

If an oxygen-containing precursor (for example a Siloxane) is used, a representative predicted empirical composition resulting from PECVD under conditions forming a hydrophobic or lubricating pH protective coating or layer would be $Si_wO_xC_yH_z$ or its equivalent SiO_xC_y as defined in the Definition Section, while a representative predicted empirical composition resulting from PECVD under conditions forming a barrier coating or layer would be SiO_x, where x in this formula is from about 1.5 to about 2.9. If a nitrogen-containing precursor (for example a silazane) is used, the predicted composition would be $Si_{w*}N_{x*}C_{y*}H_{z*}$, i.e. in $Si_wO_xC_yH_z$ or its equivalent SiO_xC_y as specified in the Definition Section, O is replaced by N and the indices for H are adapted to the higher valency of N as compared to O (3 instead of 2. The latter adaptation will generally follow the ratio of w, x, y and z in a Siloxane to the corresponding indices in its aza counterpart. In a particular aspect of the invention, $Si_{w*}N_{x*}C_{y*}H_{z*}$ (or its equivalent $SiN_{X*}C_{y*}$) in which w*, x*, y*, and z* are defined the same as w, x, y, and z for the siloxane counterparts, but for an optional deviation in the number of hydrogen atoms.

One type of precursor starting material having the above empirical formula is a linear siloxane, for example a material having the following formula:



in which each R is independently selected from alkyl, for example methyl, ethyl, propyl, isopropyl, butyl, isobutyl, t-butyl, vinyl, alkyne, or others, and n is 1, 2, 3, 4, or greater, optionally two or greater. Several examples of contemplated linear siloxanes are

hexamethyldisiloxane (HMDSO),

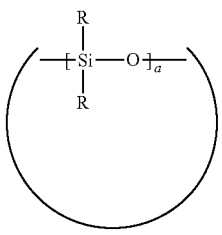
octamethyltrisiloxane,

decamethyltetrasiloxane,

dodecamethylpentasiloxane,

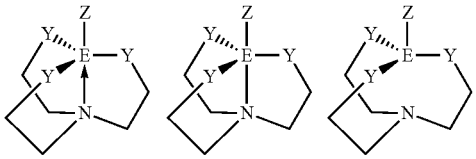
or combinations of two or more of these. The analogous silazanes in which —NH— is substituted for the oxygen atom in the above structure are also useful for making analogous pH protective coating or layers or coating or layers. Several examples of contemplated linear silazanes are octamethyltrisilazane, decamethyltetrasilazane, or combinations of two or more of these.

Another type of precursor starting material, among the preferred starting materials in the present context, is a monocyclic siloxane, for example a material having the following structural formula:



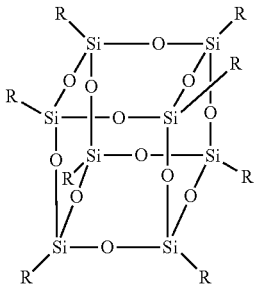
in which R is defined as for the linear structure and "a" is from 3 to about 10, or the analogous monocyclic silazanes. Several examples of contemplated hetero-substituted and unsubstituted monocyclic siloxanes and silazanes include 1,3,5-trimethyl-1,3,5-tris(3,3,3-trifluoropropyl)methyl]cyclotrisiloxane 2,4,6,8-tetramethyl-2,4,6,8-tetravinylcyclotetrasiloxane, pentamethylcyclopentasiloxane, pentavinylpentamethylcyclopentasiloxane, hexamethylcyclotrisiloxane, hexaphenylcyclotrisiloxane, octamethylcyclotetrasiloxane (OMCTS), octaphenylcyclotetrasiloxane, decamethylcyclopentasiloxane dodecamethylcyclohexasiloxane, methyl(3,3,3-trifluoropropl)cyclosiloxane, Cyclic organosilazanes are also contemplated, such as Octamethylcyclotetrasilazane, 1,3,5,7-tetravinyl-1,3,5,7-tetramethylcyclotetrasilazane hexamethylcyclotrisilazane, octamethylcyclotetrasilazane, decamethylcyclopentasilazane, dodecamethylcyclohexasilazane, or combinations of any two or more of these.

Another type of precursor starting material, among the preferred starting materials in the present context, is a polycyclic siloxane, for example a material having one of the following structural formulas:



in which Y can be oxygen or nitrogen, E is silicon, and Z is a hydrogen atom or an organic substituent, for example alkyl such as methyl, ethyl, propyl, isopropyl, butyl, isobutyl, t-butyl, vinyl, alkyne, or others. When each Y is oxygen, the respective structures, from left to right, are a Silatrane, a Silquasilatrane, and a Silproatrane. When Y is nitrogen, the respective structures are an azasilatrane, an azasilquasiatrane, and an azasilproatrane.

Another type of polycyclic siloxane precursor starting material, among the preferred starting materials in the present context, is a polysilsesquioxane, with the empirical formula $RSiO_{1.5}$ and the structural formula:



T_8 cube

in which each R is a hydrogen atom or an organic substituent, for example alkyl such as methyl, ethyl, propyl, isopropyl, butyl, isobutyl, t-butyl, vinyl, alkyne, or others. Two commercial materials of this sort are SST-eM01 poly(methylsilsesquioxane), in which each R is methyl, and SST-3 MH1.1 poly(Methyl-Hydridosilsesquioxane), in which 90% of the R groups are methyl, 10% are hydrogen atoms. This material is available in a 10% solution in tetrahydrofuran, for example. Combinations of two or more of these are also contemplated. Other examples of a contemplated precursor are methylsilatrane, CAS No. 2288-13-3, in which each Y is oxygen and Z is methyl, methylazasilatrane, poly(methylsilsesquioxane) (for example SST-eM01 poly(methylsilsesquioxane)), in which each R optionally can be methyl, SST-3 MH1.1 poly(Methyl-Hydridosilsesquioxane) (for example SST-3 MH1.1 poly(Methyl-Hydridosilsesquioxane)), in which 90% of the R groups are methyl and 10% are hydrogen atoms, or a combination of any two or more of these.

The analogous polysilsesquiazanes in which —NH— is substituted for the oxygen atom in the above structure are also useful for making analogous pH protective coating or layer. Examples of contemplated polysilsesquiazanes are a poly(methylsilsesquiazane), in which each R is methyl, and a poly(Methyl-Hydridosilsesquiazane, in which 90% of the R groups are methyl, 10% are hydrogen atoms. Combinations of two or more of these are also contemplated.

One particularly contemplated precursor for the barrier coating or layer according to the present invention is a linear siloxane, for example is HMDSO. One particularly contemplated precursor for the pH protective coating or layer and the pH protective coating or layer according to the present invention is a cyclic siloxane, for example octamethylcyclotetrasiloxane (OMCTS).

It is believed that the OMCTS or other cyclic siloxane molecule provides several advantages over other siloxane materials. First, its ring structure results in a less dense pH protective coating or layer (as compared to pH protective coating or layer prepared from HMDSO). The molecule also allows selective ionization so that the final structure and chemical composition of the pH protective coating or layer can be directly controlled through the application of the plasma power. Other organosilicon molecules are readily ionized (fractured) so that it is more difficult to retain the original structure of the molecule.

In any of the PECVD methods according to the present invention, the applying step optionally can be carried out by vaporizing the precursor and providing it in the vicinity of the substrate. For example, OMCTS is usually vaporized by heating it to about 50° C. before applying it to the PECVD apparatus.

Cyclic organosilicon precursors, in particular monocyclic organosilicon precursors (like the monocyclic precursors listed elsewhere in present description), and specifically OMCTS, are particularly suitable to achieve a pH protective coating or layer.

Other Components of PECVD Reaction Mixture and Ratios of Components For pH Protective Coating or Layer

Generally, for a pH protective coating or layer, O_2 can be present in an amount (which can, for example be expressed by the flow rate in sccm) which is less than one order of magnitude greater than the organosilicon amount. In contrast, in order to achieve a barrier coating or layer, the amount of O_2 typically is at least one order of magnitude higher than the amount of organosilicon precursor. In particular, the volume ratio (in sccm) of organosilicon precursor to O_2 for a pH protective coating or layer can be in the range from 0.1:1 to 10:1, optionally in the range from 0.3:1 to 8:1, optionally in the range from 0.5:1 to 5:1, optionally from 1:1 to 3:1. The presence of the precursor and O_2 in the volume ratios as given in Tables 9-11 is specifically suitable to achieve a pH protective coating or layer.

In one aspect of the invention, a carrier gas is absent in the reaction mixture, in another aspect of the invention, it is present. Suitable carrier gases include Argon, Helium and

other noble gases such as Neon and Xenon. When the carrier gas is present in the reaction mixture, it is typically present in a volume (in sccm) exceeding the volume of the organosilicon precursor. For example, the ratio of the organosilicon precursor to carrier gas can be from 1:1 to 1:50, optionally from 1:5 to 1:40, optionally from 1:10 to 1:30. One function of the carrier gas is to dilute the reactants in the plasma, encouraging the formation of a coating or layer on the substrate instead of powdered reaction products that do not adhere to the substrate and are largely removed with the exhaust gases.

Since the addition of Argon gas improves the pH protective performance (see the working examples below), it is believed that additional ionization of the molecule in the presence of Argon contributes to providing lubricity. The Si—O—Si bonds of the molecule have a high bond energy followed by the Si—C, with the C—H bonds being the weakest. pH protective appears to be achieved when a portion of the C—H bonds are broken. This allows the connecting (cross-linking) of the structure as it grows. Addition of oxygen (with the Argon) is understood to enhance this process. A small amount of oxygen can also provide C—O bonding to which other molecules can bond. The combination of breaking C—H bonds and adding oxygen all at low pressure and power leads to a chemical structure that is solid while providing lubricity.

In any of embodiments, one preferred combination of process gases includes octamethylcyclotetrasiloxane (OMCTS) or another cyclic siloxane as the precursor, in the presence of oxygen as an oxidizing gas and argon as a carrier gas. Without being bound to the accuracy of this theory, the inventors believe this particular combination is effective for the following reasons. The presence of O_2, N_2O, or another oxidizing gas and/or of a carrier gas, in particular of a carrier gas, for example a noble gas, for example Argon (Ar), is contemplated to improve the resulting pH protective coating or layer.

Some non-exhaustive alternative selections and suitable proportions of the precursor gas, oxygen, and a carrier gas are provided below.

OMCTS: 0.5-5.0 sccm

Oxygen: 0.1-5.0 sccm

Argon: 1.0-20 sccm

PECVD Apparatus for Forming pH Protective Coating or Layer

The low-pressure PECVD process described in U.S. Pat. No. 7,985,188 can be used to provide the barrier, lubricity, and pH protective coating or layers described in this specification. A brief synopsis of that process follows, with reference to present FIGS. **4-6**.

A PECVD apparatus suitable for performing the present invention includes a vessel holder **50**, an inner electrode defined by the probe **108**, an outer electrode **160**, and a power supply **162**. The pre-assembly **12** seated on the vessel holder **50** defines a plasma reaction chamber, which optionally can be a vacuum chamber. Optionally, a source of vacuum **98**, a reactant gas source **144**, a gas feed (probe **108**) or a combination of two or more of these can be supplied.

The PECVD apparatus can be used for atmospheric-pressure PECVD, in which case the plasma reaction chamber defined by the pre-assembly **12** does not need to function as a vacuum chamber.

Referring to FIGS. **4-6**, the vessel holder **50** comprises a gas inlet port **104** for conveying a gas into the pre-assembly **12** seated on the opening **82**. The gas inlet port **104** has a sliding seal provided for example by at least one O-ring **106**, or two O-rings in series, or three O-rings in series, which can seat against a cylindrical probe **108** when the probe **108** is inserted through the gas inlet port **104**. The probe **108** can be a gas inlet conduit that extends to a gas delivery port at its distal end **110**. The distal end **110** of the illustrated embodiment can be inserted deep into the pre-assembly **12** for providing one or more PECVD reactants and other precursor feed or process gases.

FIG. **6** shows additional optional details of the coating station **60** that are usable, for example, with all the illustrated embodiments. The coating station **60** can also have a main vacuum valve **574** in its vacuum line **576** leading to the pressure sensor **152**. A manual bypass valve **578** is provided in the bypass line **580**. A vent valve **582** controls flow at the vent **404**.

Flow out of the PECVD gas or precursor source **144** is controlled by a main reactant gas valve **584** regulating flow through the main reactant feed line **586**. One component of the gas source **144** is the organosilicon liquid reservoir **588**. The contents of the reservoir **588** are drawn through the organosilicon capillary line **590**, which is provided at a suitable length to provide the desired flow rate. Flow of organosilicon vapor is controlled by the organosilicon shut-off valve **592**. Pressure is applied to the headspace **614** of the liquid reservoir **588**, for example a pressure in the range of 0-15 psi (0 to 78 cm. Hg), from a pressure source **616** such as pressurized air connected to the headspace **614** by a pressure line **618** to establish repeatable organosilicon liquid delivery that is not dependent on atmospheric pressure (and the fluctuations therein). The reservoir **588** is sealed and the capillary connection **620** is at the bottom of the reservoir **588** to ensure that only neat organosilicon liquid (not the pressurized gas from the headspace **614** flows through the capillary tube **590**. The organosilicon liquid optionally can be heated above ambient temperature, if necessary or desirable to cause the organosilicon liquid to evaporate, forming an organosilicon vapor. To accomplish this heating, the pH protective coating or layer apparatus can advantageously include heated delivery lines from the exit of the precursor reservoir to as close as possible to the gas inlet into the syringe. Preheating is useful, for example, when feeding OMCTS.

Oxygen is provided from the oxygen tank **594** via an oxygen feed line **596** controlled by a mass flow controller **598** and provided with an oxygen shut-off valve **600**.

Optionally in any embodiment, other precursor, reactant, and/or carrier gas reservoirs such as **602** can be provided to supply additional materials if needed for a particular deposition process. Each such reservoir such as **602** has the appropriate feed line **604** and shut-off valve **606**.

Referring especially to FIG. **4**, the processing station **28** can include an electrode **160** fed by a radio frequency power supply **162** for providing an electric field for generating plasma within the pre-assembly **12** during processing. In this embodiment, the probe **108** is also electrically conductive and is grounded, thus providing a counter-electrode within the pre-assembly **12**. Alternatively, in any embodiment the outer electrode **160** can be grounded and the probe **108** directly connected to the power supply **162**.

In the embodiment of FIGS. **4-6**, the outer electrode **160** can either be generally cylindrical as illustrated in FIGS. **4** and **5** or a generally U-shaped elongated channel as illustrated in FIG. **6** (FIG. **5** being an embodiment of the section taken along section line A-A of FIG. **4**). Each illustrated embodiment has one or more sidewalls, such as **164** and **166**, and optionally a top end **168**, disposed about the pre-assembly **12** in close proximity.

Specific PECVD conditions for application of a pH protective coating or layer are provided below.

Plasma Conditions for pH Protective Coating or Layer

Typically, the plasma in the PECVD process is generated at RF frequency. For providing a pH protective coating or layer on the interior of a vessel by a plasma reaction carried out within the vessel, the plasma of any embodiment can be generated with an electric power of from 0.1 to 500 W, optionally from 0.1 to 400 W, optionally from 0.1 to 300 W, optionally from 1 to 250 W, optionally from 1 to 200 W, even optionally from 10 to 150 W, optionally from 20 to 150 W, for example of 40 W, optionally from 40 to 150 W, even optionally from 60 to 150 W. The ratio of the electrode power to the plasma volume can be less than 100 W/ml, optionally is from 5 W/ml to 75 W/ml, optionally is from 6 W/ml to 60 W/ml, optionally is from 10 W/ml to 50 W/ml, optionally from 20 W/ml to 40 W/ml. These power levels are suitable for applying pH protective coating or layers or coating or layers to syringes and cartridges and sample tubes and pharmaceutical packages or other vessels of similar geometry having a void volume of 5 mL in which PECVD plasma is generated. It is contemplated that for larger or smaller objects the power applied, in Watts, should be increased or reduced accordingly to scale the process to the size of the substrate.

Exemplary reaction conditions for preparing a pH protective coating or layer according to the present invention in a 3 ml sample size syringe with a ⅛" diameter tube (open at the end) are as follows:

Flow Rate Ranges:
OMCTS: 0.5-10 sccm
Oxygen: 0.1-10 sccm
Argon: 1.0-200 sccm
Power: 0.1-500 watts
Specific Flow Rates:
OMCTS: 2.0 sccm
Oxygen: 0.7 sccm
Argon: 7.0 sccm
Power: 3.5 watts

The pH protective coating or layer and its application are described in more detail below. A method for applying the coating or layer includes several steps. A vessel wall is provided, as is a reaction mixture comprising plasma forming gas, i.e. an organosilicon compound gas, optionally an oxidizing gas, and optionally a hydrocarbon gas.

Plasma is formed in the reaction mixture that is substantially free of hollow cathode plasma. The vessel wall is contacted with the reaction mixture, and the pH protective coating or layer of SiO_x is deposited on at least a portion of the vessel wall.

In certain embodiments, the generation of a uniform plasma throughout the portion of the vessel to be coated is contemplated, as it has been found in certain instances to generate a better pH protective coating or layer. Uniform plasma means regular plasma that does not include a substantial amount of hollow cathode plasma (which has a higher emission intensity than regular plasma and is manifested as a localized area of higher intensity interrupting the more uniform intensity of the regular plasma).

Container Closure Integrity

Optionally in any embodiment, the container closure integrity of the capped pre-assembly can be measured before, during, or after the application of a vapor-deposited coating or layer.

A container closure integrity (CCI) test is a non-destructive leak test method intended for use in manufacturing as an in-process package integrity check. A CCI test is intended to determine the microbial barrier properties of a sterile container indirectly, as by measuring a physical property that is correlated with microbial barrier properties. Respecting the present capped pre-assemblies, the CCI test is a preliminary test that determines the package integrity of the front end of the syringe, in particular the barrel, dispensing portion, and cap. This CCI test can be carried out on the unfilled but capped pre-assembly to determine whether these components of the package have the appropriate barrier properties.

Since in the present method the dispensing portion and cap are already present and installed when the barrier coatings are applied to the barrel, the container closure integrity of the pre-assembly can be verified to assure, before the capped pre-assembly is filled with an expensive pharmaceutical preparation, that these components do not have any defects that would cause the filled package to be rejected.

Moreover, the test optionally can be carried out using the same equipment commonly used for many vapor deposition processes, in particular a vacuum arrangement to draw a vacuum on the syringe barrel and associated dispensing portion and cap, which can be combined with leak detection equipment as shown in the first working example below. Thus, the CCI test can be carried out quickly, which is very important to allow the test to be carried out on each package as it is manufactured.

Example 1 below shows a CCI test conducted on the pre-assembly in 20 seconds. More broadly, it is contemplated for any embodiment that the present CCI test can be carried out in a time between 1 second and 60 seconds, alternatively between 2 seconds and 60 seconds, alternatively between 3 seconds and 60 seconds, alternatively between 4 seconds and 60 seconds, alternatively between 5 seconds and 60 seconds, alternatively between 6 seconds and 60 seconds, alternatively between 7 seconds and 60 seconds, alternatively between 8 seconds and 60 seconds, alternatively between 9 seconds and 60 seconds, alternatively between 10 seconds and 60 seconds, alternatively between 11 second and 60 seconds, alternatively between 12 seconds and 60 seconds, alternatively between 13 seconds and 60 seconds, alternatively between 14 seconds and 60 seconds, alternatively between 15 seconds and 60 seconds, alternatively between 16 seconds and 60 seconds, alternatively between 17 seconds and 60 seconds, alternatively between 18 seconds and 60 seconds, alternatively between 19 seconds and 60 seconds, alternatively between 1 second and 20 seconds, alternatively between 2 seconds and 20 seconds, alternatively between 3 seconds and 20 seconds, alternatively between 4 seconds and 20 seconds, alternatively between 5 seconds and 20 seconds, alternatively between 6 seconds and 20 seconds, alternatively between 7 seconds and 20 seconds, alternatively between 8 seconds and 20 seconds, alternatively between 9 seconds and 20 seconds, alternatively between 10 seconds and 20 seconds, alternatively between 11 seconds and 20 seconds, alternatively between 12 seconds and 20 seconds, alternatively between 13 seconds and 20 seconds, alternatively between 14 seconds and 20 seconds, alternatively between 15 seconds and 20 seconds, alternatively between 16 seconds and 20 seconds, alternatively between 17 seconds and 20 seconds, alternatively between 18 seconds and 20 seconds, alternatively between 19 seconds and 20 seconds, alternatively between 20 seconds and 60 seconds, alternatively between 10 seconds and 50 seconds, alternatively between 10 seconds and 40 seconds, alternatively between 10 seconds and 30 seconds, alternatively between 10 seconds and 20 seconds, alternatively between 20 seconds and 50 sec-

onds, alternatively between 20 seconds and 40 seconds, alternatively between 20 seconds and 30 seconds.

In any embodiment, the CCI test can be carried out, while drawing at least a partial vacuum through the barrel opening (**32**), by measuring the pressure decay of gas drawn from the barrel opening (**32**) and any leakage paths.

In any embodiment, the CCI test can be carried out by comparing the pressure decay of gas to a predetermined standard to determine the container closure integrity of the capped pre-assembly.

In any embodiment, the pressure decay can be measured with sufficient precision to detect a pressure decay due to an intact container versus a container having a single perforation in the cap having a diameter of 5 microns, alternatively 4 microns, alternatively 3 microns, alternatively 2 microns, alternatively 1.8 microns, alternatively 1 micron, alternatively 0.5 microns, alternatively 0.3 microns, alternatively 0.1 microns.

In any embodiment, the pressure decay can be measured within a time between 1 second and 60 seconds, alternatively between 2 seconds and 60 seconds, alternatively between 3 seconds and 60 seconds, alternatively between 4 seconds and 60 seconds, alternatively between 5 seconds and 60 seconds, alternatively between 6 seconds and 60 seconds, alternatively between 7 seconds and 60 seconds, alternatively between 8 seconds and 60 seconds, alternatively between 9 seconds and 60 seconds, alternatively between 10 seconds and 60 seconds, alternatively between 11 seconds and 60 seconds, alternatively between 12 seconds and 60 seconds, alternatively between 13 seconds and 60 seconds, alternatively between 14 seconds and 60 seconds, alternatively between 15 seconds and 60 seconds, alternatively between 16 seconds and 60 seconds, alternatively between 17 seconds and 60 seconds, alternatively between 18 seconds and 60 seconds, alternatively between 19 seconds and 60 seconds, alternatively between 20 seconds and 60 seconds, alternatively between 10 seconds and 50 seconds, alternatively between 10 seconds and 40 seconds, alternatively between 10 seconds and 30 seconds, alternatively between 10 seconds and 20 seconds.

In any embodiment, the pressure decay of gas drawn from the barrel opening (**32**) and any leakage paths can be measured before applying a vapor-deposited coating or layer.

In any embodiment, the pressure decay of gas drawn from the barrel opening (**32**) and any leakage paths can be measured while applying a vapor-deposited coating or layer.

In any embodiment, the pressure decay of gas drawn from the barrel opening (**32**) and any leakage paths can be measured after applying a vapor-deposited coating or layer.

Measurement of Coating or Layer Thickness

The thickness of a PECVD coating or layer such as the pH protective coating or layer, the barrier coating or layer, and/or a composite of any two or more of these coatings or layers can be measured, for example, by transmission electron microscopy (TEM). An exemplary TEM image for a pH protective coating or layer is shown in FIG. **21**. An exemplary TEM image for an SiO_2 barrier coating or layer is shown in FIG. **22**.

The TEM can be carried out, for example, as follows. Samples can be prepared for Focused Ion Beam (FIB) cross-sectioning in two ways. Either the samples can be first coated with a thin coating or layer of carbon (50-100 nm thick) and then coated with a sputtered coating or layer of platinum (50-100 nm thick) using a K575X Emitech pH protective coating or layer system, or the samples can be coated directly with the pH protective sputtered Pt coating or layer. The coated samples can be placed in an FEI FIB200 FIB system. An additional coating or layer of platinum can be FIB-deposited by injection of an organometallic gas while rastering the 30 kV gallium ion beam over the area of interest. The area of interest for each sample can be chosen to be a location half way down the length of the syringe barrel. Thin cross sections measuring approximately 15 μm ("micrometers") long, 2 μm wide and 15 μm deep can be extracted from the die surface using an in-situ FIB lift-out technique. The cross sections can be attached to a 200 mesh copper TEM grid using FIB-deposited platinum. One or two windows in each section, measuring about 8 μm wide, can be thinned to electron transparency using the gallium ion beam of the FEI FIB.

Cross-sectional image analysis of the prepared samples can be performed utilizing either a Transmission Electron Microscope (TEM), or a Scanning Transmission Electron Microscope (STEM), or both. All imaging data can be recorded digitally. For STEM imaging, the grid with the thinned foils can be transferred to a Hitachi HD2300 dedicated STEM. Scanning transmitted electron images can be acquired at appropriate magnifications in atomic number contrast mode (ZC) and transmitted electron mode (TE). The following instrument settings can be used.

Instrument	Scanning Transmission Electron Microscope
Manufacturer/Model	Hitachi HD2300
Accelerating Voltage	200 kV
Objective Aperture	#2
Condenser Lens 1 Setting	1.672
Condenser Lens 2 Setting	1.747
Approximate Objective Lens Setting	5.86
ZC Mode Projector Lens	1.149
TE Mode Projector Lens	0.7
Image Acquisition	
Pixel Resolution	1280 × 960
Acquisition Time	20 sec.(x4

For TEM analysis the sample grids can be transferred to a Hitachi HF2000 transmission electron microscope. Transmitted electron images can be acquired at appropriate magnifications. The relevant instrument settings used during image acquisition can be those given below.

Instrument	Transmission Electron Microscope
Manufacturer/Model	Hitachi HF2000
Accelerating Voltage	200 kV
Condenser Lens 1	0.78
Condenser Lens 2	0
Objective Lens	6.34
Condenser Lens Aperture	#1
Objective Lens Aperture for imaging	#3
Selective Area Aperture for SAD	N/A

Any of the above methods can also include as a step forming a coating or layer on the exterior outer wall of a pre-assembly **12**. The exterior coating or layer optionally can be a barrier coating or layer, optionally an oxygen barrier coating or layer, or optionally a water barrier coating or layer. The exterior coating or layer can also be an armor coating or layer that protects the outer wall of a pre-assembly **12**. One example of a suitable exterior coating or layer is polyvinylidene chloride, which functions both as a water barrier and an oxygen barrier. Optionally, the exterior coating or layer can be applied as a water-based coating or

layer. The exterior coating or layer optionally can be applied by dipping the vessel in it, spraying it on the pharmaceutical package or other vessel, or other expedients.

PECVD Treated Pharmaceutical Packages or Other Vessels Coated Pharmaceutical Packages or Other Vessels

Pharmaceutical packages **210** or other vessels, such as a prefilled syringe (schematically shown in FIG. **7**) or cartridge are contemplated having a barrier coating or layer such as **30** at least partially covered by a pH protective coating or layer such as **34**.

The pharmaceutical package **210** as shown in any embodiment, for example FIG. **7**, comprises a pre-assembly **12**; optionally a barrier coating or layer such as **30** on the vessel or vessel part; a pH protective coating or layer such as **34** on the vessel, vessel part, or barrier coating or layer; and a pharmaceutical composition or other fluid material **40** contained within the vessel.

The barrier coating or layer such as **30** can be an SiO_x barrier coating or layer applied as described in any embodiment of this specification or in U.S. Pat. No. 7,985,188. For example, the barrier coating or layer such as **30** of any embodiment can be applied at a thickness of at least 2 nm, or at least 4 nm, or at least 7 nm, or at least 10 nm, or at least 20 nm, or at least 30 nm, or at least 40 nm, or at least 50 nm, or at least 100 nm, or at least 150 nm, or at least 200 nm, or at least 300 nm, or at least 400 nm, or at least 500 nm, or at least 600 nm, or at least 700 nm, or at least 800 nm, or at least 900 nm. The barrier coating or layer can be up to 1000 nm, or at most 900 nm, or at most 800 nm, or at most 700 nm, or at most 600 nm, or at most 500 nm, or at most 400 nm, or at most 300 nm, or at most 200 nm, or at most 100 nm, or at most 90 nm, or at most 80 nm, or at most 70 nm, or at most 60 nm, or at most 50 nm, or at most 40 nm, or at most 30 nm, or at most 20 nm, or at most 10 nm, or at most 5 nm thick. Specific thickness ranges composed of any one of the minimum thicknesses expressed above, plus any equal or greater one of the maximum thicknesses expressed above, are expressly contemplated. The thickness of the SiO_x or other barrier coating or layer can be measured, for example, by transmission electron microscopy (TEM), and its composition can be measured by X-ray photoelectron spectroscopy (XPS). The pH protective coating or layer described herein can be applied to a variety of pharmaceutical packages or other vessels made from plastic or glass, for example to plastic tubes, vials, and syringes and cartridges.

The pH protective coating or layer such as **34** can be an SiO_xC_y pH protective coating or layer applied as described in any embodiment of this specification. For example, the vapor deposited coating or layer, here a pH protective coating or layer such as **34**, comprises or consists essentially of a coating or layer of SiO_xC_y applied over the barrier coating or layer **30** to protect at least a portion of the barrier coating or layer from the pharmaceutical preparation such as **40** in FIG. **7**. The pH protective coating or layer such as **34** is provided, for example, by applying one of the described precursors on or in the vicinity of a substrate in a PECVD process, providing a pH protective coating or layer. The coating or layer can be applied, for example, at a thickness of 1 to 5000 nm, or 10 to 1000 nm, or 10 to 500 nm, or 10 to 200 nm, or 20 to 100 nm, or 30 to 1000 nm, or 30 to 500 nm thick, or 30 to 1000 nm, or 20 to 100 nm, or 80 to 150 nm, and crosslinking or polymerizing (or both) the pH protective coating or layer, optionally in a PECVD process, to provide a protected surface.

Although not intending to be bound according to the accuracy of the following theory, the inventors contemplate that the pH protective coating or layer, applied over an SiO_x barrier coating or layer on a vessel wall, functions at least in part by passivating the SiO_x barrier coating or layer surface against attack by the contents of the vessel, as well as providing a more resistant or sacrificial independent coating or layer to isolate the SiO_x barrier coating or layer from the contents of the vessel. It is thus contemplated that the pH protective coating or layer can be very thin, and even so improve the shelf life of the pharmaceutical package.

Another expedient contemplated here, for adjacent coating or layers of SiO_x and a pH protective coating or layer, is a graded composite of SiO_x and $Si_wO_xC_y$, or its equivalent SiO_xC_y, as defined in the Definition Section. A graded composite can be separate coating or layers of a pH protective and/or barrier coating or layer or coating or layer with a transition or interface of intermediate composition between them, or separate coating or layers of a pH protective and/or hydrophobic coating or layer and SiO_x with an intermediate distinct pH protective coating or layer of intermediate composition between them, or a single coating or layer that changes continuously or in steps from a composition of a pH protective and/or hydrophobic coating or layer to a composition more like SiO_x, going through the pH protective coating or layer in a normal direction.

The grade in the graded composite can go in either direction. For example, the composition of SiO_x can be applied directly to the substrate and graduate to a composition further from the surface of a pH protective coating or layer, and optionally can further graduate to another type of coating or layer, such as a hydrophobic coating or layer or a pH protective coating or layer. Additionally, in any embodiment an adhesion coating or layer, for example $Si_wO_xC_y$, or its equivalent SiO_xC_y, optionally can be applied directly to the substrate before applying the barrier coating or layer. A graduated pH protective coating or layer is particularly contemplated if a coating or layer of one composition is better for adhering to the substrate than another, in which case the better-adhering composition can, for example, be applied directly to the substrate. It is contemplated that the more distant portions of the graded pH protective coating or layer can be less compatible with the substrate than the adjacent portions of the graded pH protective coating or layer, since at any point the pH protective coating or layer is changing gradually in properties, so adjacent portions at nearly the same depth of the pH protective coating or layer have nearly identical composition, and more widely physically separated portions at substantially different depths can have more diverse properties. It is also contemplated that a pH protective coating or layer portion that forms a better barrier against transfer of material to or from the substrate can be directly against the substrate, to prevent the more remote pH protective coating or layer portion that forms a poorer barrier from being contaminated with the material intended to be barred or impeded by the barrier.

The applied coating or layers or coating or layers, instead of being graded, optionally can have sharp transitions between one coating or layer and the next, without a substantial gradient of composition. Such pH protective coating or layer can be made, for example, by providing the gases to produce a coating or layer as a steady state flow in a non-plasma state, then energizing the system with a brief plasma discharge to form a coating or layer on the substrate. If a subsequent pH protective coating or layer is to be applied, the gases for the previous pH protective coating or layer are cleared out and the gases for the next pH protective coating or layer are applied in a steady-state fashion before energizing the plasma and again forming a distinct coating

or layer on the surface of the substrate or its outermost previous pH protective coating or layer, with little if any gradual transition at the interface.

Vessel Made Of Glass

Another embodiment is a pharmaceutical package **210** as shown in any embodiment, for example FIG. **7**, comprising a barrel **14** and/or piston **36** and/or plunger rod **38** made of glass; optionally a barrier coating or layer such as **30**, a pH protective coating or layer **30** (if a sole layer) or **34** (if formed over a barrier layer) and a pharmaceutical composition or preparation or other fluid material **40** contained within the vessel. In this embodiment a barrier coating or layer is optional because a glass vessel wall in itself is an extremely good barrier coating or layer. It is contemplated to optionally provide a barrier coating or layer primarily to provide isolation: in other words, to prevent contact and interchange of material of any kind, such as ions of the glass or constituents of the pharmaceutical composition or preparation between the vessel wall and the contents of the vessel. The pH protective coating or layer as defined in this specification is contemplated to perform the isolation function independently, at least to a degree. This protection coating or layer is contemplated to provide a useful function on glass in contact with the pharmaceutical composition or preparation, as the present working examples show that borosilicate glass, commonly used today for pharmaceutical packaging, is dissolved by a fluid composition having a pH exceeding 5. Particularly in applications where such dissolution is disadvantageous or perceived to be disadvantageous, the present pH protective coating or layers or coating or layers will find utility.

The vessel can be made, for example of glass of any type used in medical or laboratory applications, such as soda-lime glass, borosilicate glass, or other glass formulations. One function of a pH protective coating or layer on a glass vessel can be to reduce the ingress of ions in the glass, either intentionally or as impurities, for example sodium, calcium, or others, from the glass to the contents of the pharmaceutical package or other vessel, such as a reagent or blood in an evacuated blood collection tube. Alternatively, a dual functional pH protective/pH protective coating or layer can be used on a glass vessel in whole or in part, such as selectively at surfaces contacted in sliding relation to other parts, to provide lubricity, for example to ease the insertion or removal of a stopper or passage of a sliding element such as a piston in a syringe, as well as to provide the isolation of a pH protective coating or layer. Still another reason to coat a glass vessel, for example with a dual functional hydrophobic and pH protective coating or layer, is to prevent a reagent or intended sample for the pharmaceutical package or other vessel, such as blood, from sticking to the wall of the vessel or an increase in the rate of coagulation of the blood in contact with the wall of the vessel, as well as to provide the isolation of a pH protective coating or layer.

A related embodiment is a barrel **14** of a syringe, cartridge, or the like as described in the previous paragraphs, in which the barrier coating or layer is made of soda lime glass, borosilicate glass, or another type of glass coating or layer on a substrate.

II. Gaseous Reactant or Process Gas Limitations of any Embodiment

Deposition Conditions of any Embodiment

The plasma for PECVD, if used, can be generated at reduced pressure and the reduced pressure can be less than 300 mTorr, optionally less than 200 mTorr, even optionally less than 100 mTorr. The physical and chemical properties of the pH protective coating or layer can be set by setting the ratio of O_2 to the organosilicon precursor in the gaseous reactant, and/or by setting the electric power used for generating the plasma.

Relative Proportions of Gases of any Embodiment

The process gas can contain this ratio of gases for preparing a pH protective coating or layer:

from 0.5 to 10 standard volumes of the precursor;
from 1 to 100 standard volumes of a carrier gas,
from 0.1 to 10 standard volumes of an oxidizing agent.

alternatively this ratio:

from 1 to 6 standard volumes of the precursor;
from 1 to 80 standard volumes of a carrier gas,
from 0.1 to 2 standard volumes of an oxidizing agent.

alternatively this ratio:

from 2 to 4 standard volumes, of the precursor;
from 1 to 100 standard volumes of a carrier gas,
from 0.1 to 2 standard volumes of an oxidizing agent.

alternatively this ratio:

from 1 to 6 standard volumes of the precursor;
from 3 to 70 standard volumes, of a carrier gas,
from 0.1 to 2 standard volumes of an oxidizing agent.

alternatively this ratio:

from 2 to 4 standard volumes, of the precursor;
from 3 to 70 standard volumes of a carrier gas,
from 0.1 to 2 standard volumes of an oxidizing agent.

alternatively this ratio:

from 1 to 6 standard volumes of the precursor;
from 1 to 100 standard volumes of a carrier gas,
from 0.2 to 1.5 standard volumes of an oxidizing agent.

alternatively this ratio:

from 2 to 4 standard volumes, of the precursor;
from 1 to 100 standard volumes of a carrier gas,
from 0.2 to 1.5 standard volumes of an oxidizing agent.

alternatively this ratio:

from 1 to 6 standard volumes of the precursor;
from 3 to 70 standard volumes of a carrier gas,
from 0.2 to 1.5 standard volumes of an oxidizing agent.

alternatively this ratio:

from 2 to 4 standard volumes of the precursor;
from 3 to 70 standard volumes of a carrier gas,
from 0.2 to 1.5 standard volumes of an oxidizing agent.

alternatively this ratio:

from 1 to 6 standard volumes of the precursor;
from 1 to 100 standard volumes of a carrier gas,
from 0.2 to 1 standard volumes of an oxidizing agent.

alternatively this ratio:

from 2 to 4 standard volumes of the precursor;
from 1 to 100 standard volumes of a carrier gas,
from 0.2 to 1 standard volumes of an oxidizing agent.

alternatively this ratio:

from 1 to 6 standard volumes of the precursor;
from 3 to 70 standard volumes of a carrier gas,
from 0.2 to 1 standard volumes of an oxidizing agent.

alternatively this ratio:

2 to 4 standard volumes, of the precursor;
from 3 to 70 standard volumes of a carrier gas,
from 0.2 to 1 standard volumes of an oxidizing agent.

alternatively this ratio:

from 1 to 6 standard volumes of the precursor;
from 5 to 100 standard volumes of a carrier gas,
from 0.1 to 2 standard volumes of an oxidizing agent.

alternatively this ratio:

from 2 to 4 standard volumes, of the precursor;
from 5 to 100 standard volumes of a carrier gas,
from 0.1 to 2 standard volumes
of an oxidizing agent.

alternatively this ratio:
from 1 to 6 standard volumes of the precursor;
from 10 to 70 standard volumes, of a carrier gas,
from 0.1 to 2 standard volumes of an oxidizing agent.
alternatively this ratio:
from 2 to 4 standard volumes, of the precursor;
from 10 to 70 standard volumes of a carrier gas,
from 0.1 to 2 standard volumes of an oxidizing agent.
alternatively this ratio:
from 1 to 6 standard volumes of the precursor;
from 5 to 100 standard volumes of a carrier gas,
from 0.5 to 1.5 standard volumes of an oxidizing agent.
alternatively this ratio:
from 2 to 4 standard volumes, of the precursor;
from 5 to 100 standard volumes of a carrier gas,
from 0.5 to 1.5 standard volumes of an oxidizing agent.
alternatively this ratio:
from 1 to 6 standard volumes of the precursor;
from 10 to 70 standard volumes, of a carrier gas,
from 0.5 to 1.5 standard volumes of an oxidizing agent.
alternatively this ratio:
from 2 to 4 standard volumes of the precursor;
from 10 to 70 standard volumes of a carrier gas,
from 0.5 to 1.5 standard volumes of an oxidizing agent.
alternatively this ratio:
from 1 to 6 standard volumes of the precursor;
from 5 to 100 standard volumes of a carrier gas,
from 0.8 to 1.2 standard volumes of an oxidizing agent.
alternatively this ratio:
from 2 to 4 standard volumes of the precursor;
from 5 to 100 standard volumes of a carrier gas,
from 0.8 to 1.2 standard volumes of an oxidizing agent.
alternatively this ratio:
from 1 to 6 standard volumes of the precursor;
from 10 to 70 standard volumes of a carrier gas,
from 0.8 to 1.2 standard volumes of an oxidizing agent.
alternatively this ratio:
2 to 4 standard volumes, of the precursor;
from 10 to 70 standard volumes of a carrier gas,
from 0.8 to 1.2 standard volumes of an oxidizing agent.

Carrier Gas of any Embodiment

The carrier gas can comprise or consist of an inert gas, for example argon, helium, xenon, neon, another gas that is inert to the other constituents of the process gas under the deposition conditions, or any combination of two or more of these.

Oxidizing Gas of any Embodiment

The oxidizing gas can comprise or consist of oxygen (O_2 and/or O_3 (commonly known as ozone)), nitrous oxide, or any other gas that oxidizes the precursor during PECVD at the conditions employed. The oxidizing gas comprises about 1 standard volume of oxygen. The gaseous reactant or process gas can be at least substantially free of nitrogen.

III. Plasma of any Embodiment

The plasma of any PECVD embodiment can be formed in the vicinity of the substrate. The plasma can in certain cases, especially when preparing a barrier coating or layer, be a non-hollow-cathode plasma. In other certain cases, especially when preparing a pH protective coating or layer, a non-hollow-cathode plasma is not desired. The plasma can be formed from the gaseous reactant at reduced pressure. Sufficient plasma generation power input can be provided to induce pH protective coating or layer formation on the substrate.

IV. RF Power of any Embodiment

The precursor can be contacted with a plasma made by energizing the vicinity of the precursor with electrodes powered at a frequency of 10 kHz to 2.45 GHz, alternatively from about 13 to about 14 MHz.

The precursor can be contacted with a plasma made by energizing the vicinity of the precursor with electrodes powered at radio frequency, optionally at a frequency of from 10 kHz to less than 300 MHz, optionally from 1 to 50 MHz, even optionally from 10 to 15 MHz, optionally at 13.56 MHz.

The precursor can be contacted with a plasma made by energizing the vicinity of the precursor with electrodes supplied with electric power at from 0.1 to 25 W, optionally from 1 to 22 W, optionally from 1 to 10 W, even optionally from 1 to 5 W, optionally from 2 to 4 W, for example of 3 W, optionally from 3 to 17 W, even optionally from 5 to 14 W, for example 6 or 7.5 W, optionally from 7 to 11 W, for example of 8 W, from 0.1 to 500 W, optionally from 0.1 to 400 W, optionally from 0.1 to 300 W, optionally from 1 to 250 W, optionally from 1 to 200 W, even optionally from 10 to 150 W, optionally from 20 to 150 W, for example of 40 W, optionally from 40 to 150 W, even optionally from 60 to 150 W.

The precursor can be contacted with a plasma made by energizing the vicinity of the precursor with electrodes supplied with electric power density at less than 10 W/ml of plasma volume, alternatively from 6 W/ml to 0.1 W/ml of plasma volume, alternatively from 5 W/ml to 0.1 W/ml of plasma volume, alternatively from 4 W/ml to 0.1 W/ml of plasma volume, alternatively from 2 W/ml to 0.2 W/ml of plasma volume, alternatively from 10 W/ml to 50 W/ml, optionally from 20 W/ml to 40 W/ml.

The plasma can be formed by exciting the reaction mixture with electromagnetic energy, alternatively microwave energy.

V. Other Process Options of any Embodiment

The applying step for applying a pH protective coating or layer to the substrate can be carried out by vaporizing the precursor and providing it in the vicinity of the substrate.

The chemical vapor deposition employed can be PECVD and the deposition time can be from 1 to 30 sec, alternatively from 2 to 10 sec, alternatively from 3 to 9 sec. The purposes for optionally limiting deposition time can be to avoid overheating the substrate, to increase the rate of production, and to reduce the use of process gas and its constituents. The purposes for optionally extending deposition time can be to provide a thicker pH protective coating or layer for particular deposition conditions.

VI. Protective Coating or Layer Properties of any Embodiment

Thickness of any Embodiment

Optionally, the pH protective coating or layer can have a thickness determined by transmission electron microscopy (TEM), of any amount stated in this disclosure.

Composition of any Embodiment

Optionally, the pH protective coating or layer can be composed of $Si_wO_xC_yH_z$ (or its equivalent SiO_xC_y) or $Si_wN_xC_yH_z$ or its equivalent SiN_xC_y), each as defined previously. The atomic ratio of Si:O:C can be determined by XPS (X-ray photoelectron spectroscopy). Taking into account the H atoms, the pH protective coating or layer may thus in one aspect have the formula $Si_wO_xC_yH_z$, or its equivalent SiO_xC_y, for example where w is 1, x is from about 0.5 to about 2.4, y is from about 0.6 to about 3, and z is from about 2 to about 9.

Typically, expressed as the formula $Si_wO_xC_y$, the atomic ratios of Si, O, and C are, as several options:

Si 100: O 50-150: C 90-200 (i.e. w=1, x=0.5 to 1.5, y=0.9 to 2);

Si 100: O 70-130: C 90-200 (i.e. w=1, x=0.7 to 1.3, y=0.9 to 2)

Si 100: O 80-120: C 90-150 (i.e. w=1, x=0.8 to 1.2, y=0.9 to 1.5)

Si 100: O 90-120: C 90-140 (i.e. w=1, x=0.9 to 1.2, y=0.9 to 1.4), or

Si 100: O 92-107: C 116-133 (i.e. w=1, x=0.92 to 1.07, y=1.16 to 1.33).

Alternatively, the pH protective coating or layer can have atomic concentrations normalized to 100% carbon, oxygen, and silicon, as determined by X-ray photoelectron spectroscopy (XPS) of less than 50% carbon and more than 25% silicon. Alternatively, the atomic concentrations are from 25 to 45% carbon, 25 to 65% silicon, and 10 to 35% oxygen. Alternatively, the atomic concentrations are from 30 to 40% carbon, 32 to 52% silicon, and 20 to 27% oxygen. Alternatively, the atomic concentrations are from 33 to 37% carbon, 37 to 47% silicon, and 22 to 26% oxygen.

Optionally, the atomic concentration of carbon in the pH protective coating or layer, normalized to 100% of carbon, oxygen, and silicon, as determined by X-ray photoelectron spectroscopy (XPS), can be greater than the atomic concentration of carbon in the atomic formula for the organosilicon precursor. For example, embodiments are contemplated in which the atomic concentration of carbon increases by from 1 to 80 atomic percent, alternatively from 10 to 70 atomic percent, alternatively from 20 to 60 atomic percent, alternatively from 30 to 50 atomic percent, alternatively from 35 to 45 atomic percent, alternatively from 37 to 41 atomic percent.

Optionally, the atomic ratio of carbon to oxygen in the pH protective coating or layer can be increased in comparison to the organosilicon precursor, and/or the atomic ratio of oxygen to silicon can be decreased in comparison to the organosilicon precursor.

Optionally, the pH protective coating or layer can have an atomic concentration of silicon, normalized to 100% of carbon, oxygen, and silicon, as determined by X-ray photoelectron spectroscopy (XPS), less than the atomic concentration of silicon in the atomic formula for the feed gas. For example, embodiments are contemplated in which the atomic concentration of silicon decreases by from 1 to 80 atomic percent, alternatively by from 10 to 70 atomic percent, alternatively by from 20 to 60 atomic percent, alternatively by from 30 to 55 atomic percent, alternatively by from 40 to 50 atomic percent, alternatively by from 42 to 46 atomic percent.

As another option, a pH protective coating or layer is contemplated that can be characterized by a sum formula wherein the atomic ratio C:O can be increased and/or the atomic ratio Si:O can be decreased in comparison to the sum formula of the organosilicon precursor.

Other pH Protective Coating or Layer Properties of any Embodiment

The pH protective coating or layer can have a density between 1.25 and 1.65 g/cm^3, alternatively between 1.35 and 1.55 g/cm^3, alternatively between 1.4 and 1.5 g/cm^3, alternatively between 1.4 and 1.5 g/cm^3, alternatively between 1.44 and 1.48 g/cm^3, as determined by X-ray reflectivity (XRR). Optionally, the organosilicon compound can be octamethylcyclotetrasiloxane and the pH protective coating or layer can have a density which can be higher than the density of a pH protective coating or layer made from HMDSO as the organosilicon compound under the same PECVD reaction conditions.

The pH protective coating or layer optionally can prevent or reduce the precipitation of a compound or component of a composition in contact with the pH protective coating or layer, in particular can prevent or reduce insulin precipitation or blood clotting, in comparison to the uncoated surface and/or to a barrier coated surface using HMDSO as precursor.

The substrate can be a pharmaceutical package or other vessel, for protecting a compound or composition contained or received in the vessel with a pH protective coating or layer against mechanical and/or chemical effects of the surface of the uncoated substrate.

The substrate can be a pharmaceutical package or other vessel, for preventing or reducing precipitation and/or clotting of a compound or a component of the composition in contact with the inner or interior surface of the vessel. The compound or composition can be a biologically active compound or composition, for example a medicament, for example the compound or composition can comprise insulin, wherein insulin precipitation can be reduced or prevented. Alternatively, the compound or composition can be a biological fluid, for example a bodily fluid, for example blood or a blood fraction wherein blood clotting can be reduced or prevented.

The pH protective coating or layer optionally can have an RMS surface roughness value (measured by AFM) of from about 5 to about 9, optionally from about 6 to about 8, optionally from about 6.4 to about 7.8. The R_a surface roughness value of the pH protective coating or layer, measured by AFM, can be from about 4 to about 6, optionally from about 4.6 to about 5.8. The R_{max} surface roughness value of the pH protective coating or layer, measured by AFM, can be from about 70 to about 160, optionally from about 84 to about 142, optionally from about 90 to about 130.

VII. Product Made of Vessel Plus Contents, Optional for any Embodiment

In any embodiment, the substrate can be a vessel having an inner or interior surface defining a lumen and an exterior surface, the pH protective coating or layer can be on the inner or interior surface of the pharmaceutical package or other vessel, and the vessel can contain a compound or composition in its lumen, for example citrate or a citrate containing composition, or for example insulin or an insulin containing composition. A prefilled syringe or cartridge is especially considered which contains injectable or other liquid drugs like insulin.

Optionally for any of the embodiments, illustrated for example in FIG. **7**, the capped pre-assembly of the Figures can be filled with a fluid material **40**. Examples of a suitable fluid composition are any one or a combination of any two or more members selected from the group recited in the claims.

As several examples, the fluid material **40** can be an inhalation anesthetic, a drug, or a diagnostic test material. Any of these fluid materials **40** can be an injectable material, a volatile material capable of being inhaled, or otherwise capable of being introduced into a subject.

EXAMPLE 1

Container Closure Integrity

A test was performed using as samples commercially obtained capped pre-assemblies with staked needles (1 ml. capacity "long" style syringes without plungers) similar to those of the present FIGS. **1-5**. The caps **28** were made of elastomeric material. Thus, the seated caps **28** of the pre-

assemblies **12** isolated the distal openings **24** due to contact between the caps **28** and the barrels **14**.

A test group of ten pre-assemblies was used as supplied, with intact caps **28**. A control group of five pre-assemblies ("perforated caps") was modified by intentionally providing one round aperture of controlled diameter through the wall of each cap **28**. The apertures of controlled diameter were made by pushing one fused silica glass capillary of known inside diameter (2 microns) through each cap. The capillaries were inserted from inside the barrel lumen **18** out through the hypodermic needle distal opening **24** and through the end of the needle cap **28**. The capillaries thus bypassed the seals created by the ribs **42** (per FIG. **3**), as well as the seals created by burying the dispensing portions **20** in the material of the caps **28**. The capillaries were then cut at both ends to ensure that the capillaries were not clogged. It is believed that the outside walls of the silica glass capillaries were essentially sealed against the material of the needle cap, thus effectively limiting leakage to flow through the internal passages of the capillaries of known internal diameter and round cross-section. This test primarily evaluated the ability of the cap **28** to prevent leakage of material from the barrel lumen.

The test was conducted using an ATC (Advanced Test Concepts, Inc.) Leak Tek mass flow leak detector. The flange end or opening **32** of each pre-assembly was sealed on a test fixture comprising a seat with an O-ring seal connected in series via the conical flow cell of the ATC mass flow leak detector to a vacuum pump, with a side passage **386** provided to bypass the ATC machine when initially pumping down the barrel lumen **18** from ambient pressure. This test set-up is illustrated schematically in FIG. 30 of U.S. Pat. No. 7,985,188, with the pre-assembly **12** serving as the vessel **358**.

The following testing conditions were used for test runs. A pre-assembly **12** was clamped against the O-ring of the test fixture using a clamping pressure of 40 psi to seat the pre-assembly on the test fixture. Then, the vacuum pump was operated for 5 sec. with the side passage **386** open to pump down the barrel lumen **18** to its initial vacuum. The side passage **386** was closed at an elapsed time set equal to zero seconds while the vacuum pump remained in operation to induce flow through the ATC machine. The test was started at an elapsed time of one second by measuring the vacuum level a first time as reported in the tables below in millibars, using the ATC machine. At an elapsed time of 21 seconds, providing a total test time of 20 sec., the test was concluded by measuring the vacuum level a second time as reported in the tables below in millibars, using the ATC machine. The difference between the 1^{st} and 2^{nd} measurements was determined for each test, reported in Tables 1 and 2, and plotted in FIG. **8** as pressure decay.

Referring to Table 1 and plot **52** presenting the data for the intact caps, the average pressure decay (in this case, more precisely, vacuum decay) was 4.8 millibars, with a maximum decay of 5.1 millibars and a standard deviation of 0.2 millibars. This maximum decay was used as a standard against which to measure the effect of introducing apertures into the intact caps.

Referring to Table 2 and plot **54** presenting the data for the perforated caps, the average pressure decay was 13.5 millibars, with a minimum decay of 11.6 millibars and a standard deviation of 2.4 millibars. Since the perforated caps clearly had a statistically significant, higher pressure decay than the intact caps, the two were easily distinguished in a 20-second test.

The pressure decay is believed to have occurred (although the invention is not limited according to the accuracy of this theory) because the initial pressure was measured after a brief period of time (one second) to allow the unit to reach a quasi-steady state. At this time, the mass flow had the indicated baseline value, believed to be related to the amount of mass extracted from the surface of container. When there was a hole in the container, by the second measurement time ambient atmosphere outside the container was pulled into the container by the vacuum, creating a larger mass flow. The amount of mass flow was related to the size of the hole. By this means a non-integral container was easily detected because it had a greater pressure decay than a predetermined standard (in this case, the standard was established by the tests on intact caps).

This method used sensitive pressure transducers to measure a pressure differential, which optionally can be converted to a mass flow rate. The mass flow rate was determined very quickly after a few seconds of drawing a vacuum on the container to be tested. This method is amenable to high speed, on-line, high sensitivity container closure integrity (CCI) testing. In every case the mass flow detector was off scale when capillaries down to 1.8 microns ID were tested. This indicates that the test can be carried out more quickly and/or with smaller capillaries than those used in this test.

A second container closure integrity test can be conducted, in which the caps **28** are perforated between the rib **42** and the portion of the cap **28** in contact with the dispensing portion **20**. This test provides a failure bypassing just the seal created by the rib **42**, thus testing the ability of the caps **28** to prevent contamination of the outside of the needle or other dispensing portion **20**. Using both the former and the latter tests, one can completely test the container closure integrity of the seal.

EXAMPLE 2

Deposition of Coating Products in Dispensing Portion Lumen **26**

The following example was carried out as described below, and shows that there was no significant increase in Si on the syringe needle based on the PECVD coating process. This example demonstrates that the interior portion of the needle did not get significantly coated during the PECVD coating process, if coated with the needle cap applied.

Two studies were untaken with 100 needles in each study.

In the first study, 96 staked-needle 1 ml capacity long style syringes, which were only coated with a barrier coating or layer **30**, and **100** uncoated but otherwise similar syringes were obtained. The needles were removed from syringes by heating the plastic needle hub and needle with a flame, then pulling the needle from the syringe with tweezers. Care was taken to secure the needle with the tweezers immediately next to the plastic hub. This ensured that if the needle was collapsed by the tweezers, the collapsed area was in the middle of the needle and both ends remained open to allow solution to access the needle. The needles were removed cleanly with little to no plastic.

The needles from the coated syringes were cut into two sections, one near the needle tip approximately 11 mm long and the other section closest to the syringe body approximately 9 mm long. This was done to determine, if Si was present, where it was in the needle. The needles were placed in labeled 5 ml COP vials with 0.1 N KOH (2.0 ml coated syringe needles and 6.0 ml uncoated syringe needles). The

vials were placed in a vacuum of approximately 28 inches Hg for one minute, to remove any air which was trapped in the needles. The vials were sealed with a 20 mm washed plastic stopper and crimped with an aluminum crimp cap. The vials were autoclaved at 121° C. for 60 minutes. After the vials had cooled to room temperature the solutions were transferred into 15 ml polypropylene tubes until testing was performed. Si in solution was performed by ICP/OES (inductively coupled plasma-optical emission spectroscopy).

The second tested utilized 97 coated staked-needle 1 ml. capacity long style syringes, tri-layer PECVD coated (with a barrier coating or layer **30**, a pH protective coating or layer **34**, and a lubricity layer as discussed in U.S. Pat. No. 7,985,188). These syringes were ethylene oxide sterilized. 100 uncoated COP 1 ml long staked needle syringes were used as a comparison. Testing was performed in the same manner as above. The results are shown in Tables 3 and 4.

The results from the first study are shown in Table 3. In that study the coated syringes had received only barrier coating. The needles from the uncoated syringes (0.155 μg/syringe) had more Si present than the needles from the coated syringes (0.102 μg/syringe) demonstrating that the coating process did not add any coating. The absence of Si from coated syringe needles is further demonstrated by the Si per unit length of needle (μg Si/mm). If a coating was present it would be expected that the portion of the needle closest to the syringe would have a higher Si per unit length than the portion of the needle furthest from the syringe. This was not observed.

The results from the second study in Table 4 again show that the difference in Si found in needles from coated syringes and needles from uncoated syringes was not significant. The amount of Si per unit length of needle was essentially the same regardless of the location of the needle.

The presence of some Si in needles was expected as stainless steel contains approximately 1% Si by weight. The weight of the needles used in these syringes was approximately 11 mg (11000 μg), therefore a Si result of 0.1-0.2 μg/syringe is not unreasonable.

It was concluded from these studies that there is no coating, or at a minimum essentially no coating, in the internal diameters of the needles of syringes coated by any of the coating processes used for the syringes tested in this study.

TABLE 1

Sample	1st (mbar)	2nd (mbar)	Delta (mbar)
1	990.7	985.8	4.9
2	990.7	985.6	5.1
3	990.7	985.7	5.0
4	991.0	986.4	4.6
5	991.5	986.8	4.7
6	991.9	987.2	4.7
7	991.2	986.2	5.0
8	991.3	986.5	4.8
9	991.8	987.4	4.4
10	992.1	987.6	4.5
Avg	991.3	986.5	4.8
Max	992.1	987.6	5.1
Min	990.7	985.6	4.4
StDev	0.5	0.7	0.2

TABLE 2

Sample	1st (mbar)	2nd (mbar)	Delta (mbar)
#1Known Failure (2 μm)	988.3	976.3	12.0
#2Known Failure (2 μm)	987.6	974.9	12.7
#3Known Failure (2 μm)	987.4	969.9	17.5
#4Known Failure (2 μm)	987.4	973.9	13.5
#5Known Failure (2 μm)	987.7	976.1	11.6
Avg	987.7	974.2	13.5
Max	988.3	976.3	17.5
Min	987.4	969.9	11.6
StDev	0.4	2.6	2.4

TABLE 3

First Test (1-PECVD coating cycle)

Syringe Sample	# of syringes	Result (μg Si/syringe)	(μg Si/mm needle)
Uncoated syringe	100	0.155	0.078
Total coated needles	96	0.102	0.050
Coated needle tip end	96	0.064	0.058
Coated syringe end	96	0.038	0.051

TABLE 4

Second Test (3- PECVD coating cycles)

Syringe Sample	# of syringes	Result (μg Si/syringe)	(μg Si/mm needle)
Uncoated syringe	100	0.220	0.011
Total coated needles	97	0.244	0.012
Coated needle tip end	97	0.123	0.011
Coated syringe end	97	0.121	0.013

The invention claimed is:

1. A method comprising:

providing a capped pre-assembly comprising:

a barrel comprising an internal wall defining a barrel lumen and a front opening through the internal wall;

a dispensing portion comprising a hypodermic needle secured to the barrel, the hypodermic needle comprising a distal opening located outside the barrel and a dispensing portion lumen communicating between the front opening of the barrel and the distal opening of the dispensing portion; and

a cap secured to the barrel and at least substantially isolating the front opening from pressure conditions outside the cap, the cap being sufficiently permeable to a sterilizing gas to sterilize the portions of the assembly isolated by the cap; and

applying a plasma enhanced chemical vapor deposition (PECVD) coating or layer directly or indirectly to at least a portion of the internal wall of the barrel, while the pre-assembly is capped and the dispensing portion lumen of the hypodermic needle is communicating between the front opening and the distal opening of the dispensing portion, under conditions effective to maintain communication between the barrel lumen and the exterior via the front opening at the end of the applying

step, in which essentially no PECVD coating is formed in the dispensing portion lumen of the hypodermic needle.

2. The method of claim **1**, further comprising, before the providing step, assembling the capped pre-assembly.

3. The method of claim **2**, further comprising, before the assembling step, forming the barrel.

4. The method of claim **3**, in which the barrel is formed by placing the dispensing portion in an injection mold and injection molding thermoplastic material about the dispensing portion, thus forming the barrel and securing the dispensing portion to the barrel.

5. The method of claim **1**, in which the cap is made of a thermoplastic elastomer.

6. The method of claim **1**, in which the cap of the pre-assembly isolates the distal opening at least partially due to: contact between the cap and the distal opening, contact between the cap and the barrel, or both.

7. The method of claim **1**, in which the barrel further comprises an opening spaced from the dispensing portion and communicating through the internal wall.

8. The method of claim **7**, in which the vapor-deposited coating or layer is applied through the opening.

9. The method of claim **8**, in which the PECVD coating or layer is applied by flowing a reactant vapor material through the opening and employing plasma enhanced chemical vapor deposition to deposit a reaction product of the reactant vapor material on the internal wall of the barrel.

10. The method of claim **1**, further comprising, while drawing at least a partial vacuum through the barrel opening, measuring the pressure decay of gas drawn from the barrel opening and any leakage paths.

11. The method of claim **10**, further comprising comparing the pressure decay of gas to a predetermined standard to determine the container closure integrity of the capped pre-assembly.

12. The method of claim **11**, in which the pressure decay is measured with sufficient precision to detect a pressure decay due to an intact container versus a container having a single perforation in the cap having a diameter of 5 microns, to 0.5 microns.

13. The method of claim **12**, in which the pressure decay is measured within a time between 1 second and 60 seconds.

14. The method of claim **10**, in which the pressure decay of gas drawn from the barrel opening and any leakage paths is measured after applying a vapor-deposited coating or layer.

15. The method of claim **1**, in which the vapor-deposited coating or layer is a barrier coating or layer.

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